DESIGN AND DEVELOPMENT OF LIGHT WEIGHT AUTOMOBILE PANELS WITH SANDWICH COMPOSITE MATERIALS

A Thesis Submitted
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF DESIGN

By

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July 2004

CERTIFICATE

This is to certify that the work contained in this thesis entitled **"Design and development of light weight automobile panels with sandwich composite materials"**, by Vinay Pahlajani has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

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ABSTRACT

The automobile industry is one of the core industries in Indian economy, whose prospect is reflective of the economic resilience of the country. With the growth of this industry there is a huge demand of vehicles with novel designs and high fuel efficiency. However, the Indian automobile manufacturers are constraining themselves to the production of limited designs, because of very high investments involved in tooling. The automobile industry in India is gradually evolving to replicate those of developed countries, where the concept of limited volume editions is prevalent.

Lightweight sandwich composite materials are finding exciting opportunities in the automotive industry as a means of increasing fuel efficiency. A subsequent amount of fuel consumption is directly related to vehicle weight, potential weight reductions stimulate usage of lightweight composite materials.

Sandwich composites made of glass fiber reinforced plastic (GFRP) skins with a low density core material in between, are capable to meet the requirements of different automobile panels. The major advantages offered by this material are light weight, high specific strength and high specific stiffness. Also, the tooling cost involved in manufacturing of composite parts is very low. This gives the designers a liberty to come up with new designs which can be very well molded with fewer numbers of parts.

In the present work light weight automobile panels are designed and developed using different sandwich materials. Encouraging results are marked in reducing the finishing operations of FRP panels. Other manufacturing processes like Resin Infusion Molding (RIM) was studied and established for obtaining better and consistent FRP parts.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

The automobile industry is one of the core industries in Indian economy, whose prospect is reflective of the economic resilience of the country. With the growth of this industry there is a huge demand of vehicles with novel designs and high fuel efficiency. However, the Indian automobile manufacturers are constraining themselves to the production of limited designs, owing to the very high investment involved in tooling. The automobile industry in India is gradually evolving to replicate those of developed countries, where the concept of limited volume editions is prevalent.

The high cost, associated with tooling for sheet metal parts, constraints the imagination of the automobile designers. The other problems associated with sheet metal body shells of vehicles like passenger cars are heavy weight, high maintenance cost and poor design flexibility. The sheet metal components are manufactured in smaller sizes to reduce tooling cost; this practice poses another problem of assembly of the panels.

1.2 LIGHT WEIGHT MATERIALS FOR AUTOMOBILES

Lightweight materials may find exciting opportunities in the automotive industry as a means of increasing fuel efficiency. A subsequent part of fuel consumption is related directly to vehicle weight. Potential weight reductions that result in improved price-performance ratio stimulate usage of lightweight materials.

The automotive industry can expect an impressive 6 to 8 percent improvement in fuel usage with a mere 10 percent reduction in vehicle weight. This translates into a reduction of around 20 kilograms of carbon dioxide per kilogram of weight reduction over the vehicle's lifetime. A survey of the European auto industry emphasizes the success of lightweight plastics in vehicle weight reduction. Lighter vehicles facilitate easier braking, reduce collision impact and provide superior driving experience.

Lightweight material's invaluable contributions extend beyond the automotive sector. Lightweight materials are successful in the aerospace industry, mass-transportation components, high-rise buildings and racecars. Such composite materials have extremely high strength-to-weight and rigidity-to-weight ratios coupled with exceptional thermal insulation properties.

1.3 FIBER REINFORCED PLASTICS (FRP)

With reduction in weight, it is also important to meet the structural and engineering requirements of the end product. Fiber Reinforced Plastics (FRP) is the best example of material which can cater to both the requirements of the end product, especially in industries like aerospace and automobiles. The scope of FRP composites in not limited to light weight and high strength but it also provides additional advantages of design flexibility and low tooling cost.

FRP composites is defined as a polymer matrix, either thermoset or thermoplastic, that is reinforced with a fiber or other reinforcing material with a sufficient aspect ratio to provide a discernable reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or aluminum. FRP composites are anisotropic where as steel or aluminum is isotropic. Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. Composites are similar to reinforced concrete where the reinforcement bars are embedded in an isotropic matrix called concrete.

1.4 SANDWICH COMPOSITES

Although fiber reinforced plastics are having many benefits, they also have certain drawbacks which may includes high cost and low production rate. One of the major problems occurs when composites are used for making thick sections. In metals sections members like I-section, H-section etc. are used to achieve high moment of inertia. Making such sections with FRP is not convenient. Conventionally monocoque structures are made to increase the thickness and hence the stiffness of a FRP component. This act increases the amount of raw material used. When conventional techniques like hand lay-up are used this process leads to very low production rates and high labor cost. With the use of monocoque structures for composite products, the weight advantage is lost. To overcome this problem **sandwich structures** are proposed, where a low density core material is sandwiched between two or more layers of FRP laminates. This helps in getting the required thickness and stiffness without increasing the weight of the product.

The sandwich technique is more prevalent in aerospace industry in form of honeycomb structures, where as for down to earth industries like automobiles other options are derived for developing light weight panels of sufficient strength and stiffness.

Figure 1.1 shows a cored laminate under a bending load. The sandwich laminate can be compared to an I-beam, in which the laminate skins act as the I-beam flange, and the core materials act as the beam's shear web. In this mode of loading it can be seen that the upper skin is put into compression, the lower skin into tension and the core into shear. It therefore follows that one of the most important properties of a core is its shear strength and stiffness.

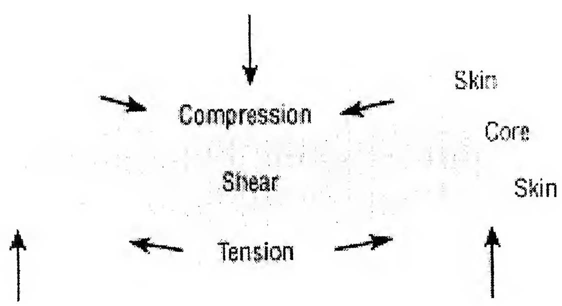


Fig. 1.1: Sandwich composite structure

In addition, particularly when using lightweight, thin laminate skins, the core must be capable of taking a compressive loading without premature failure. This helps to prevent the thin skins from wrinkling, and failing in a buckling mode.

1.5 COMPOSITION

Composites are composed of resins, reinforcements, fillers, and additives. Each of these constituent materials or ingredients plays an important role in the processing and final performance of the end product. The resin or polymer is the "glue" that holds the composite together and influences the physical properties of the end product. The reinforcement provides the mechanical strength. The fillers and additives are used as process or performance aids to impart special properties to the end product.
The mechanical properties and composition of FRP composites can be tailored for their intended use. Important considerations for the design of composite products include:

- Type of fiber reinforcement
- Percentage of resin or fiber volume
- Orientation of fiber (0^{o}, 90^{o}, +/- 45^{o} or a combination of these)
- Type of resin
- Type of core material
- Cost of product
- Volume of production (to help determine the best manufacturing method)
- Manufacturing process
- Service conditions

1.5.1 Resins

The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage. Resins are divided into two major groups known as thermoset and thermoplastic. Thermoplastic resins become soft when heated, and may be shaped or molded while in a heated semi-fluid state and become rigid when cooled. Thermoset resins, on the other hand, are usually liquids or low melting point solids in their initial

form. When used to produce finished goods, these thermosetting resins are "cured" by the use of a catalyst, heat or a combination of the two. Once cured, solid thermoset resins cannot be converted back to their original liquid form. Unlike thermoplastic resins, cured thermosets will not melt and flow but will soften when heated (and lose hardness) and once formed they cannot be reshaped.

The most common thermosetting resins used in the composites industry are unsaturated polyesters, epoxies, vinyl esters and phenolics. There are differences between these groups that must be understood to choose the proper material for a specific application.

1.5.2 Reinforcements

The primary function of reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction. Reinforcements can be oriented to provide tailored properties in the direction of the loads imparted on the end product. Reinforcements can be both natural and man-made. Many materials are capable of reinforcing polymers. Some materials, such as the cellulose in wood, are naturally occurring products. Most commercial reinforcements, however, are man-made. Of these, by far the largest volume reinforcement measured either in quantity consumed or in product sales, is glass fiber. Other composite reinforcing materials include carbon, aramid, UHMW (ultra high molecular weight) polyethylene, polypropylene, polyester and nylon. More specialized reinforcements for high strength and high temperature use include metals and metal oxides such as those used in aircraft or aerospace applications.

The mechanical properties of FRP composites are dependent on the type, amount, and orientation of fiber that is selected for a particular service. There are many commercially available reinforcement forms to meet the design requirements of the user. The ability to tailor the fiber architecture allows for optimized performance of a product that translates to weight and cost savings.

1.5.3 Core Materials

As discussed above, for increasing the moment of inertia of the structure, it is important to use a core material between two or more skin laminates of FRP. As shown in Figure 1.1 core material is mainly subject to shear load. But when using lightweight, thin laminate skins, the core must be capable of taking a compressive loading without premature failure. Ranges of material such as polyurethane foam, balsa wood and polystyrene beads are available to be used as sandwich; the selection of core depends on the desired properties of the final product. The desired attributes of a core material are explained in Chapter 3.

1.5.4 Fillers

Use of inorganic fillers in composites is increasing. Fillers not only reduce the cost of composites, but also frequently impart performance improvements that might not otherwise be achieved by the reinforcement and resin ingredients alone. Fillers can improve mechanical properties including fire and smoke performance by reducing organic content in composite laminates. Also, filled resins shrink less than unfilled resins, thereby improving the dimensional control of molded parts. Important properties, including water resistance, weathering, surface smoothness, stiffness, dimensional stability and temperature resistance, can all be improved through the proper use of fillers. Calcium carbonate, Alumina trihydrate and Calcium sulfate are some of the commonly used fillers.

1.5.5 Additives and Modifiers

A wide variety of additives are used in composites to modify material properties and tailor the laminate's performance. Although these materials are generally used in relatively low quantity by weight compared to resins, reinforcements and fillers, they perform critical functions.

Catalysts, Promoters, Inhibitors

In polyesters, the most important additive is catalyst or initiator. Typically, organic peroxide such as methylethylketone peroxide (MEKP) is used for room temperature

cured processes, or benzoyl peroxide is added to the resin for heat-cured molding. When triggered by heat, or used in conjunction with a promoter (such as cobalt napthenate), peroxides convert to a reactive state (exhibiting free radicals), causing the unsaturated resin to react (cross-link) and become solid. Some additives such as TBC (tertiary butyl catechol) are used to slow the rate of reaction and are called inhibitors. Accelerators such as DMA (dimethyl aniline) speed curing.

Colorants

Colorants are often used in composites to provide color throughout the part. Additives can be mixed in as part of the resin or applied as part of the molding process (as a gel coat). Also, a wide range of coatings can be applied after molding.

Release Agents

Release agents facilitate removal of parts from molds. These products can be added to the resin, applied to molds, or both. Zinc stearate is a popular mold release agent that is mixed into resin for compression molding. Waxes, silicones and other release agents may be applied directly to the surface of molds.

Thixotropic agents

In some processes such as hand lay-up or spray-up, thixotropic agents may be used. When "at rest", resins containing thixotropic agents remain at elevated viscosities. This reduces the tendency of the liquid resin to flow or drain from vertical surfaces. When the resin is subjected to shear, the viscosity is reduced and the resin can be easily sprayed or brushed on the mold. Fumed silica and certain clays are common thixotropic agents.

Additives and modifier ingredients expand the usefulness of polymers, enhance their processability or extend product durability. While additives and modifiers often increase the cost of the basic material system, these materials always improve cost/performance.

1.6 MANUFACTURING PROCESS

For designing composite products, it is very important to understand various manufacturing processes and the advantages offered by them. There are two general divisions of composites manufacturing processes. **Open molding** (sometimes called contact molding) and **closed molding**. With open molding, the gel coat and laminate are exposed to the atmosphere during the fabrication process. In closed molding, the composite is processed in a two-sided mold set, or within a vacuum bag. In present works Hand lay-up technique is used for part fabrication.

1.6.1 Hand lay-up

Hand lay-up is the most conventional technique of composite manufacturing; it is also called contact molding. It is a production technique suitable for prototypes and low volume production of FRP parts. The composite parts fabricated by hand lay-up have a nice smooth surface on one side and a very rough one on the other.

The fibers are manually placed on a one-sided gel coated male or female mold. A matrix of thermosetting resin (polyester, epoxy etc.) is rolled onto the fibers using a hand roller or brush. More layers can be added and, after curing, the composite part can be removed from the mold.

It is easy to control the fiber orientation in hand lay-up technique. Furthermore, the process is very flexible as it can produce from very small, up to very large part of different geometries. The cycle time per part is very long, and only small series can be produced. The cost of the production equipment is very low.

1.7 BENEFITS

FRP sandwiched composites have many benefits to their selection and use. The selection of the materials depends on the performance and intended use of the product. The composites designer can tailor the performance of the end product with proper selection of materials. It is important to understand the application environment, load performance and durability requirements of the product. A summary of composite material benefits include:

- Light weight
- High strength-to-weight ratio
- Directional strength
- Corrosion resistance
- Weather resistance
- Dimensional stability
  - low thermal conductivity
  - low coefficient of thermal expansion
- Non-magnetic
- High impact strength
- High dielectric strength (insulator)
- Low maintenance
- Long term durability
- Small to large part geometry possible
- Tailored surface finish

Chapter 2

AUTOMOBILE REQUIREMENTS AND CASE STUDY

2.1 INTRODUCTION

As discussed in Chapter1, FRP composites have many benefits to their selection and use. The selection of the materials depends on the performance and intended use of the product. It is important to understand the application environment, load performance and durability requirements of the product. The advantages of sandwiched composites over sheet metal and monocoque FRP structures are also well defined.

In order to exploit the advantages of sandwich composite structures, for automobile industry, it is important to understand the requirement of different automobile panels. Different automotive components have different desirable properties. These requirements can be met by using different materials or manufacturing processes. These requirements mainly include impact resistance, light weight, stiffness of panels, surface finish, U.V stability, heat resistance, cost, etc.

Sandwich composites offer various advantages, which can result in light weight and high fuel efficiency of automobiles. These advantages mainly include high specific strength, high specific stiffness and capability of achieving directional properties. Figure 2.1 to 2.3 shows different views of body panels of a sports car.

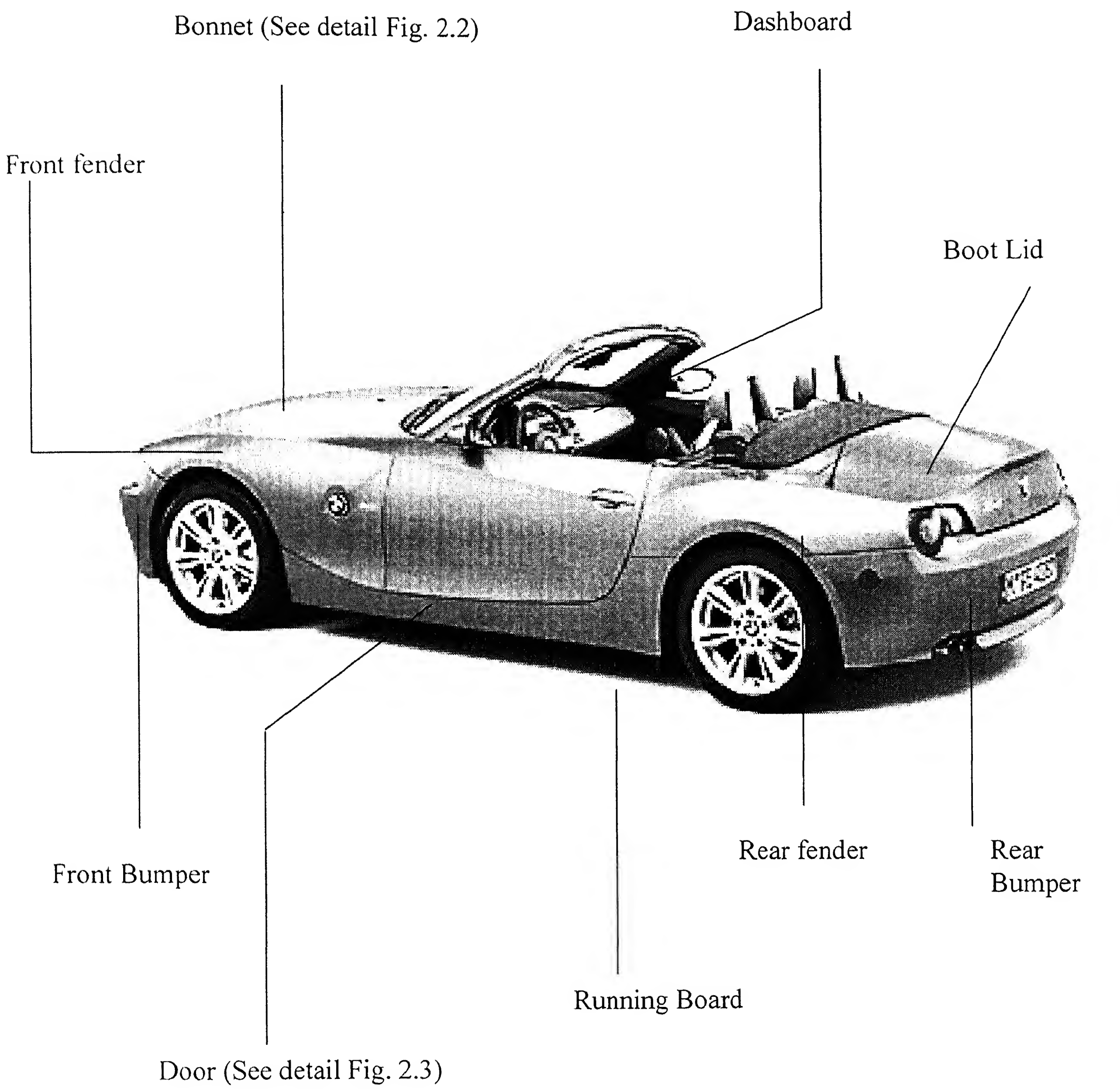


Fig. 2.1: Different body panels of a Car

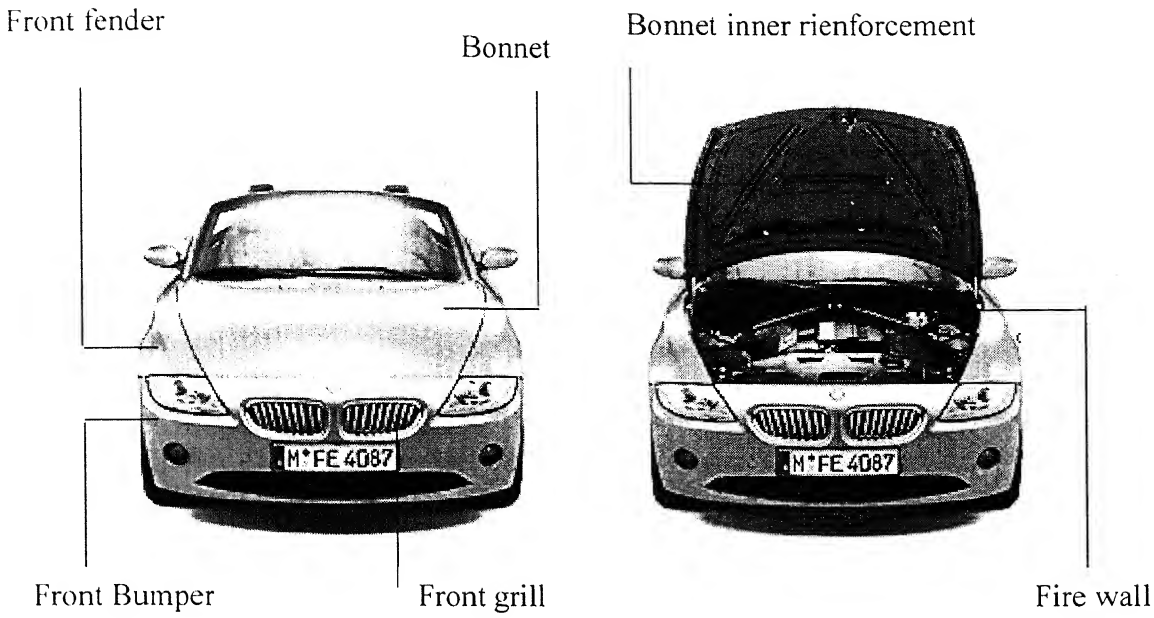


Fig.2: Front view of Car

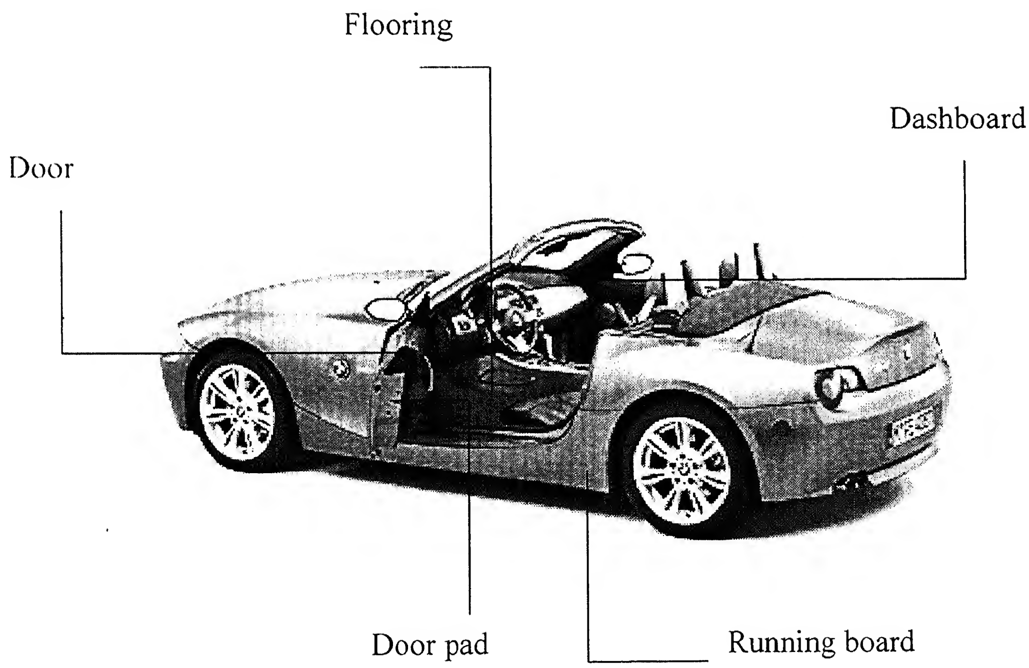


Fig.2.3: Another view of Car

2.2 AUTOMOBILE BODY PANELS

An automobile body shell is made up of many panels. Each panel serves a different purpose. These panels can be categorized on the basis of the function of a particular part or the desirable properties of that component. In automobile prototypes made of mild steel, almost all the panels are made up of same material and with similar manufacturing process. Composite design gives the liberty to select the material and manufacturing process for the component according to its desired properties. The key components of the auto body shell are discussed below (Figs. 2.1-2.3).

Fenders

Fenders are the side panels of a car, both at front and rear of the vehicle. Fenders are directly exposed to external impacts. It should be strong, stiff and stable under ultra violet (U.V) light.

Bonnet/engine cover

Bonnet is the front opening of the vehicle, usually acts as an engine cover. It is a dynamic part and involves mountings and locking arrangements. It should be light weight, stiff, heat resistant. Also it should not allow radiation losses, should take care of static charges developed by the engine and should be U.V stable.

Doors

It is one of the most critical component of the vehicle. It involves mechanisms for glass movement, inside-outside locking arrangements and mountings. It is a dynamic part and is subject to static and impact loadings very frequently.

Its two face construction poses problems, when prototyped in sheet metal. A door should be strong, stiff, light weight and dimensionally stable.

Bumpers

Bumpers are the exterior panels of a vehicle, which acts as a guard for the vehicle body. Front and rear bumpers of the vehicle are designed to be the first member to encounter any impact. Major attributes of this component are impact resistance, stiffness and U.V stability.

Running board

This exterior body panel runs along the length of the vehicle. The door frame of the vehicle is a part of running board. It can be manufactured as a single piece with vehicle flooring. The desirable properties of this component are high impact strength and capability to take static loads.

Fire wall

Firewall separates the engine area and the cabin area of the vehicle. It can also be fabricated as one piece with vehicle flooring. It should be heat resistant.

Front Grill

The front grill is meant for providing air passage to the radiator. However, it is a sharp styling feature for the front face lift of the vehicle. The grills are usually of intricate geometries.

Door Pads

Door pads are the interior cladding of the vehicle door. It is a nonstructural component, with forms and textures matching to the upholstery of the vehicle.
It accommodates the mountings for door locking and glass winding mechanisms. Desired features of door pad are aesthetic appeal and capability to take different textures.

Dashboard

Dashboard is the same category of component as door pads. It contributes to the upholstery of the vehicle and features very intricate shapes and geometries. It is a nonstructural member which accommodates equipments and mechanisms like audio-video console, meters-gauges and air bags for the safety of the passengers. The desirable properties of this component are aesthetic appeal and capability to take different textured finishes.

Apart from these requirements, all the body panels have some common desired attributes like light weight, surface finish and U.V stability for exterior components. According to these requirements the designer can tailor the

performance of the end product with proper selection of materials and manufacturing process.

2.3 CASE STUDY

Composite materials have been considered the "material of choice" in some application of automotive industry. It can meet the automotive requirements of light weight, high surface finish, styling details and customized parts. The use of composite materials is more prevalent in low volume productions like commercial vehicles and sports cars.

To understand the composite design for automobile body shells, a case study has been done. The car selected for analysis is a European sports car made up of composite materials. The car is a bench mark for vehicles of this category and the complete body shell weighs less than 100 kgs.

The vehicle components are divided in three board parts (Fig. 2.4). The design for manufacturing and design for assembly is taken care by exploiting the advantages of composite materials. The car is having fewer numbers of panels. The components like engine cover, bumper and fenders are integrated to one.

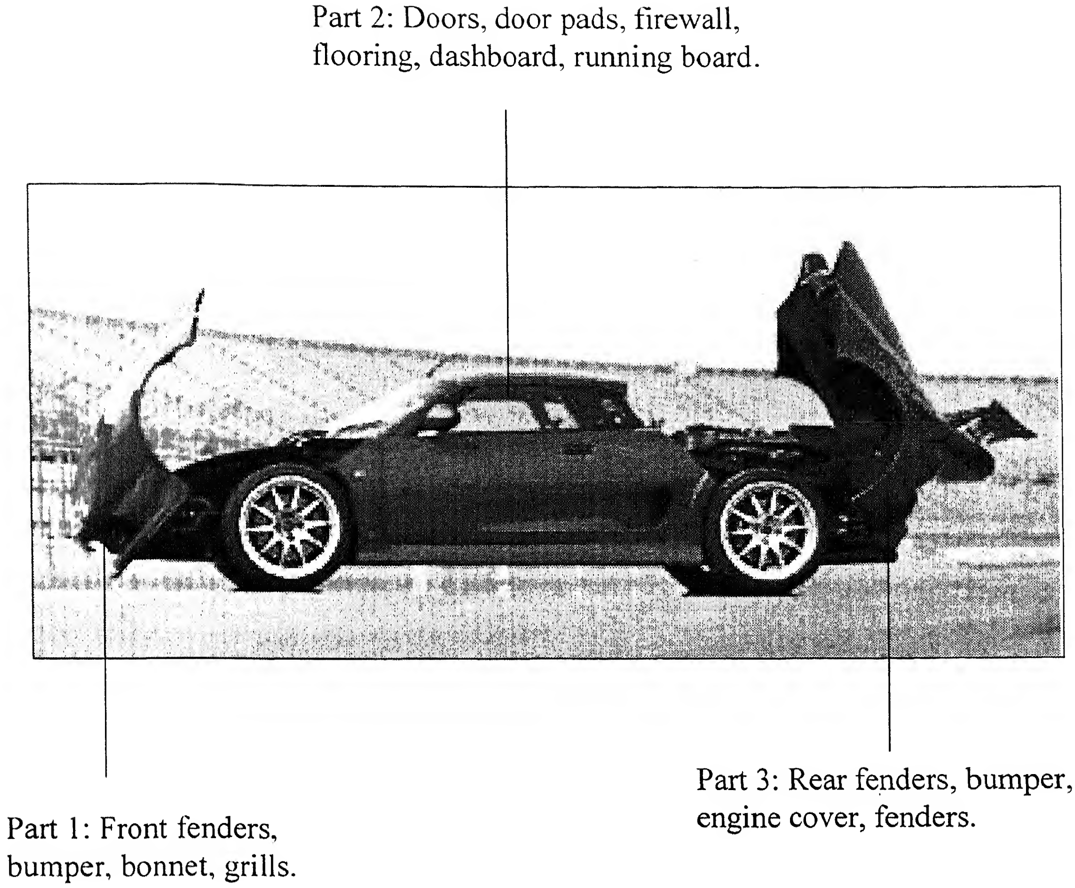
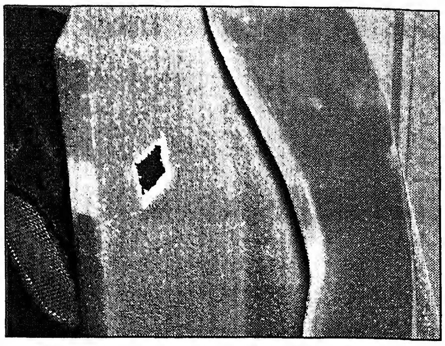


Fig. 2.4: Body panels are divided in three main parts.

2.3.1 Part 1

As shown in Figure 2.4, Part 1 of the vehicle comprises of front fenders, bonnet, bumper and grills of the vehicle in an integrated form. A study has been done to analyze the material and process involved in manufacturing of this part. Material samples were taken from different sections of this part.

Figure 2.5 shows the cutout sections of material samples from the inner flanges of the panel. The sample was analyzed and it was found that chopped strand mat (CSM) glass fiber is used as skin material and polyester based core mat as a sandwich material (Fig. 2.6). The detailed manufacturing process and properties of core mats are explained in Chapter 4.



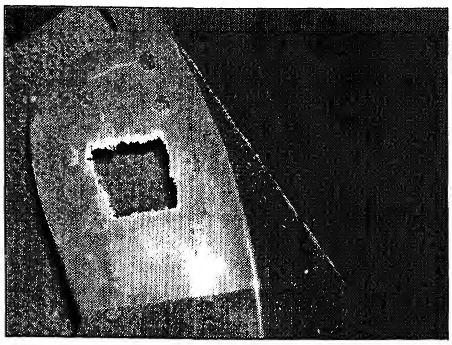


Fig. 2.5: Cutout sections of material samples from the inner flanges of the panel.

The inner surface of the panel was ground to analyze the rough surface at the inner face of the panel and presence of core mat at different sections.
It was found that the rough surface is due to the conductive electrometric paint, over the final skin of CSM glass fiber (Fig. 2.7).

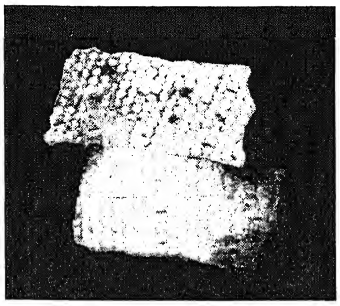


Fig. 2.6: Material sample

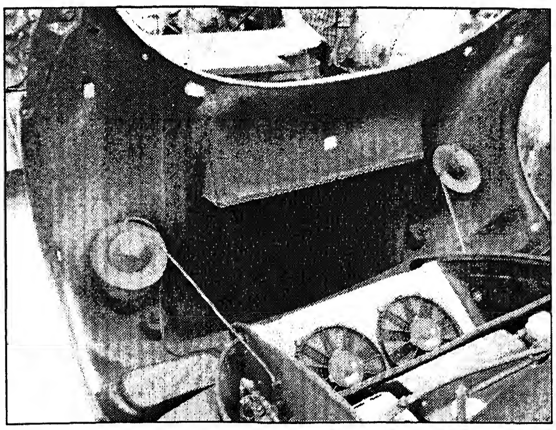


Fig. 2.7: Inner rough surface of the panel

The rough surface of conductive paint helps in relieving the static charges developed when engine runs at high speed. Also it increases the heat resistance of the panel.

2.3.2 Part 2

As shown in Figure 2.4, Part 2 of the vehicle comprises of main body shell. Firewall, flooring and running board of the vehicle are in an integrated form. The doors and door pads are mounted separately on the body shell. The complete body frame is mounted on a roll cage structure which is made up or tubular bars. Material samples were taken at different sections and it was found that the part is fabricated as a monocoque structure of CSM glass fiber and polyester resin (Fig. 2.8).

Fig. 2.8: Cutout sections of material samples from the body panel.

The doors of the car are made up of long woven glass fibers. A door is fabricated in two parts and then joined. The door pads are made up of low surface density CSM glass fibers with core mat as a sandwich (Fig. 2.9).

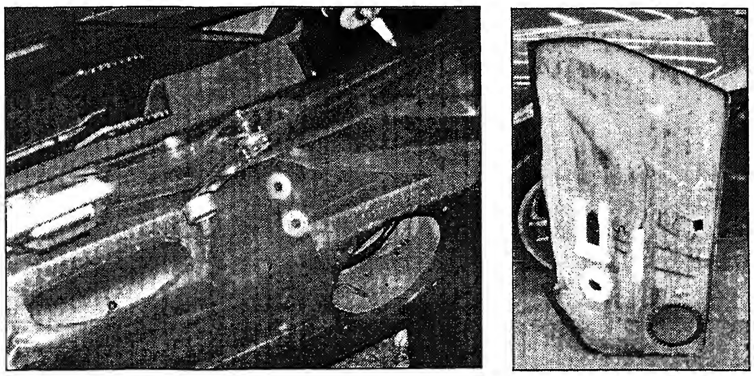


Fig. 2.9: Inner view of door and door pad

2.3.3 Part 3

Part 3 of the car (Fig. 2.4) is very much similar to Part 1 (Fig. 2.4). The panel is made up of CSM glass fiber composite, with core mat as a sandwich material. This part acts as an engine cover of the vehicle. An aluminized glass fabric sheet is provided on the inner surface of the panel to reduce the radiation losses (Fig. 2.10).

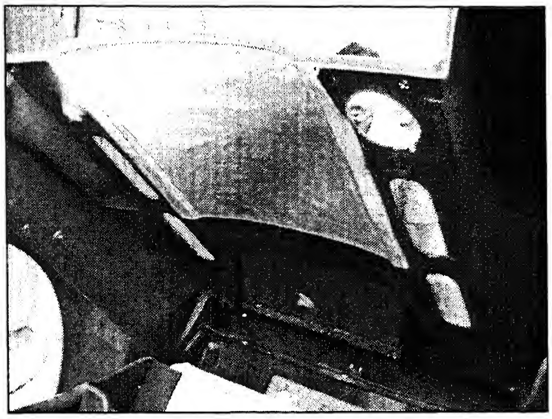


Fig. 2.10: Aluminized glass fiber sheet on inner side of panel.

2.4 CONCLUSION

The over all body shell of the vehicle weighs less than 100 kgs which makes it a bench mark in its class. It is mostly made from sandwiched panels of polymer composites. The body panels are meets all the requirements of specific parts. The panels possess high impact strength and stiffness.

The design for manufacturing and design for assembly is taken care by exploiting the advantages of composite materials. Several components of a conventional car are replaced by fewer and larger parts of GFRP.

Chapter 3

PRODUCT DEVELOPMENT WITH POLYURETHANE FOAM SANDWICHED STRUCTURES

3.1 INTRODUCTION

In the previous chapters the importance of sandwiched structures for composite materials were discussed and a strong need of these structures was identified in automobile industry. The theoretical advantages over monocoque structures and strength to thickness relationship were also explained. In the present chapter the supremacy of sandwiched structures over conventional monocoque components is established with help of products developed using a core material, and a generalized design process is illustrated.

3.1.1 Desired attributes of a core material

The first step of designing a sandwich panel is the selection of core material. According to the desirable properties of a product to be fabricated, the desired attributes of a core material can be counted as:

- **Geometry of the part to be fabricated:** The thickness of the core material is an important factor.

- **Curvatures required to be molded:** The capability of the core material to take different curvatures (single/double) and shapes.

- **Structural requirements:** The density of the core material and its capability to take shear stress caused by transverse loads.

- **Adhesion properties with the laminates:** Adhesion of core material with impregnated skin sheets of glass fibers.

- **Permeability:** Permeability of the core material to allow the resin transfer. The effect on flow rates of resin is also to be considered before material selection, if used for a vacuum assisted manufacturing process like RIM.

- **Cost:** Cost estimation should be done per unit volume.

- **Effect on production time**

3.1.2 Polyurethane (PU) foam as a sandwich material

PU foam is one of the most popular sandwich materials, and we can find its application in different industries; for example, the material is used as a sandwich core for critical components like helicopter blades. As discussed in the previous chapter (Requirements of automobiles and case studies) the desirable properties of different automobile panels can be met by this material, when used as a core. Its credibility as a sandwich can be established by comparing its properties with the desired attributes of a core material:

For different geometries and curvatures

PU foam can be used as a core in either liquid or solid initial states. For flat sections ready made sheets of foam of required density can be used. Intricate geometries and curvatures are achieved by using raw materials available in liquid forms. They are mixed and poured/injected between the two skins of FRP, the liquid foams up and fills the cavity.

Structural requirements

The structural requirements of a component can be met by using appropriate density of PU foam. Rigid foams are recommended for sustaining shear stresses, which are usually highest at the neutral axis of a section. In a sandwiched core panel, the neutral axis falls within the foam.

Adhesion properties with laminate

PU foam has reasonably good adhesion with GFRP impregnated sheets. Experiments were carried out and it was observed that the adhesion increases by increasing the density of foam in constraint.

Cost and production time

Along with increased stiffness and strength, PU foam also gives cost advantage. The material cost per unit volume is low as compared to monocoque GFRP structures. Its capability to form thick sections increases the production rate and hence labor cost is also reduced.

3.1.3 Composition and preparation

PU foam is prepared from a two component mixture of polyol and isocynate. The two are mixed thoroughly in liquid state with the help of a stirrer. The mixture starts creaming within few seconds (creaming time) and then starts foaming up with a very high speed (foaming time). The same process is accomplished with the help of a foaming machine.
The foaming reaction is carried out in presence of few other chemicals like blowing agents, surfactants etc. In the present work standard materials have been used, having appropriate quantity of additives already mixed in it. Standard materials are mixed in ratio 1:1. The curing and creaming time can be controlled by additives and different compositions of raw materials. For high quality products, preparation of foam by foaming machine and injection with appropriate pressure is recommended.

3.2 DEVELOPMENT OF TEST PRODUCTS

In the following exercise sandwiched components are developed for a live project in favor of DC Design, Mumbai. Components chosen for development are bonnet and a driver door of a bus. Components developed are dynamic, involves mechanisms and are most critical for weight and strength point of view. In the early stages several test products were fabricated to get acquainted with the sandwich configuration.

3.2.1 Test product 1- Motorbike Cowl

The test product was made to experiment the foaming reaction and to learn the complexity involved with the flow of PU foam in intricate shapes and sharp corners. The product selected was a front cowl of a motorbike. Another important objective was to the adhesion properties of PU foam with the layers of GFRP, the skin of the product.

For preparing the test sample, chopped strands mat glass fiber layers (area density 300 gms/m^2), impregnated with polyester resin, were laid on both sides of a split die. The die was also prepared with GFRP using hand lay-up technique. A two component mixture of PU foam was mixed (ratio 1:1) and poured in the cavity between the split die. The quantity of foam poured was as per the volume of the cavity. A slightly higher volume of liquid foam was poured, consequently the density of foam was increased under the constraints of GFRP skins. Material with free foam density of 35 kg/ m^3 was used for the purpose. Fig 4.1 shows the section of mobike cowl with FRP skin layers in red.

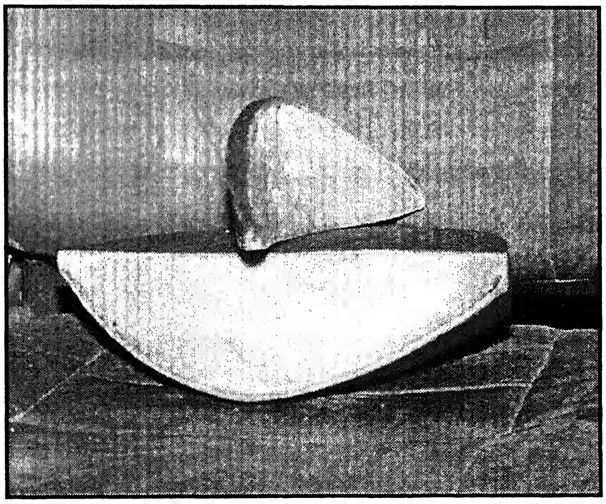


Fig 3.1: Section view of foamed structure, with red color GFRP skin and cream color PU foam.

The following important attributes were observed:

- The adhesion of foam with GFRP skins increases by increasing its density due to constraints imposed by GFRP skin, supported on rigid surface of the die.
- The flow of foam is proper to intricate corners.
- Risers should be provided to avoid entrapment of air.

3.2.2 Test product 2- Door Pocket

Door pocket for a driver door of a mini bus was selected as the second test product (Figs.4.2 & 4.3). The purpose of the test product was to observe the effect of skin thickness on a foam sandwiched structure, by using only one very thin layer of glass fiber mat (35 gms/m^2 surface density) as skin material and PU foam (free foam density 35 kg/ m^3) in between for sandwiching.

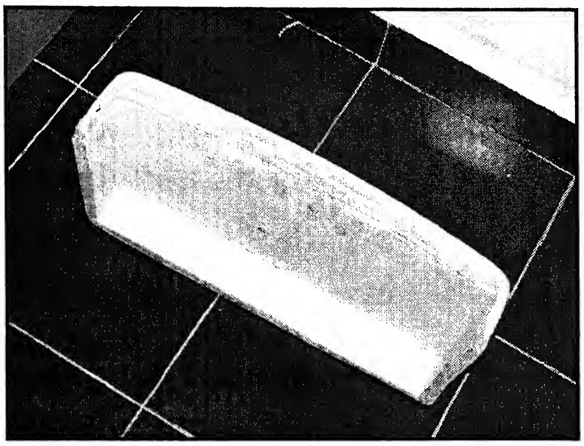


Fig 3.2: The Door Pocket

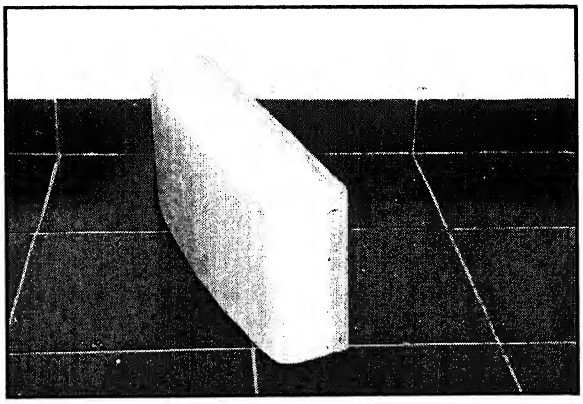


Fig 3.3: Another view of The Door Pocket

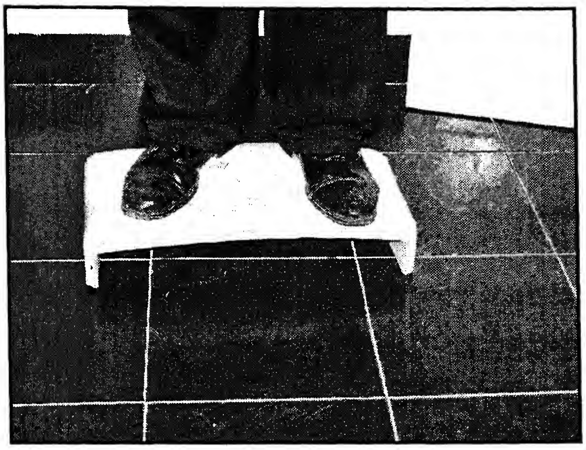


Fig 3.4: Door Pocket testing

The process was carried out in the very same manner as in case of first test product, and the product was then tested under different indigenous loading conditions. For example, a man of about 60 Kg weight stood on it (Fig.4.4); it was found to be stiff and strong.

The following important attributes were observed:

- The strength of the pocket is more in thicker sandwiched section as mentioned theoretically.
- The weight of the pocket comes out to be 600 gms which was about one third of the monocoque prototype of the same door pocket.
- The major weight and strength of the pocket is contributed by foam only.
- The strength of the pocket is good enough, and the same configuration can be used to develop interiors of automobiles.
- The pocket is not good in piercing strength, because GFRP skin used is very thin.

3.3 DEVELOPMENT OF BONNET

As mentioned in Chapter 1, GFRP panels have several advantages over sheet metal components used for automobile prototyping. Super cars like Ferrari are using carbon fiber body shells to reduce the vehicle weight. This also gives the ease of fabrication for low volume production. The design and styling flexibility is also provided by the use of GFRP panels, as it has the capability of being molded into intricate shapes with a high consistency. The low tooling cost involved with FRP molds, gives the opportunity to come up with novel designs very frequently.

The bonnet is developed at DC Design, Mumbai. The sheet metal prototype of the bonnet is available. The design specifications are to retain the exterior geometry of the existing bonnet (sheet metal prototype) and to develop a light weight bonnet with sandwich composite materials. It should have sufficient strength and stiffness. Proper mounting provisions should be done. Also, the hinges used for mounting should be compatible to other components of the bus.

3.3.1 Process Involved

Before designing a product for sandwiching process, few things should to be taken care of, as constraints or critical areas. In case of bonnet also, few design changes were made in order to exploit the best advantages of sandwiched composites. The critical areas involved are the stiffness of the panel, the inner reinforcement as in case of sheet metal component and the mounting of hinges and locks (Figs. 3.5, 3.6 & 3.7). The development of bonnet is carried out with hand lay-up technique, and is sandwiched with polyurethane foam (PU). There are three major steps involved in fabrication of bonnet with sandwiched GFRP:

- Preparation of Pattern
- Preparation of Mold
- Preparation of Panel

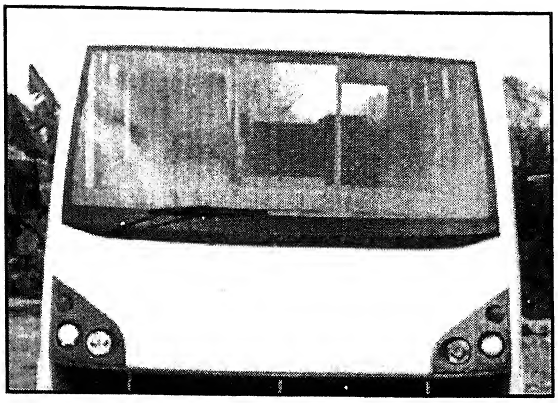


Fig 3.5: Bonnet profile.

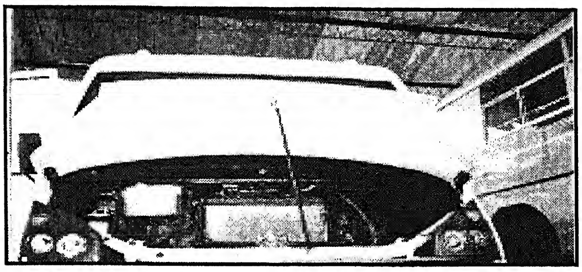


Fig 3.6: Inner side of bonnet showing reinforcement.

Fig 3.7: Hinges of bonnet.

Preparation of the Pattern

A pattern of the required panel (bonnet) is prepared with combination of FRP skin and a mild steel structure. The design of inner structure of the pattern is done in such a way that it should not interfere in the engine area and should meet the requirements of the core material (PU foam).The exterior skin of the pattern is made exactly same as metal prototype of the bonnet. A sheet metal reinforcing structure (Fig. 3.8) is then joined with

the exterior FRP skin (Fig. 3.9), to get a pattern for the bonnet. The pattern is then finished with fillers and primer to get an excellent finish (Fig. 3.10).

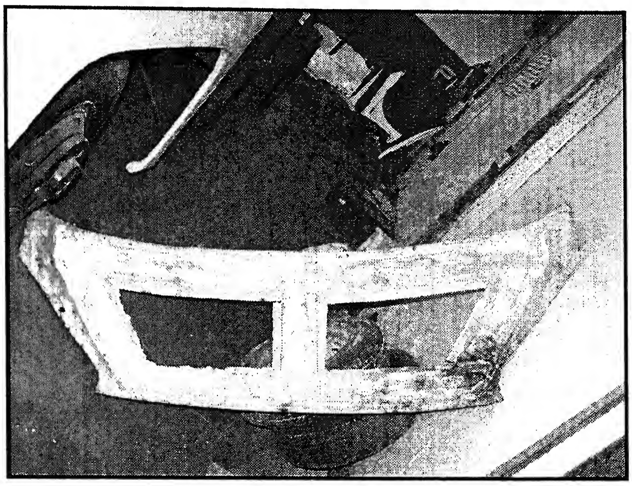


Fig 3.8: Metal frame reinforcing member for the pattern

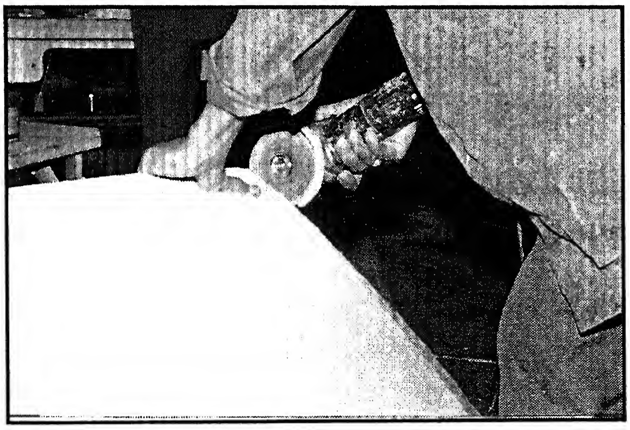


Fig 3.9: Grinding done on bonnet pattern for finishing the edges of exterior FRP skin.

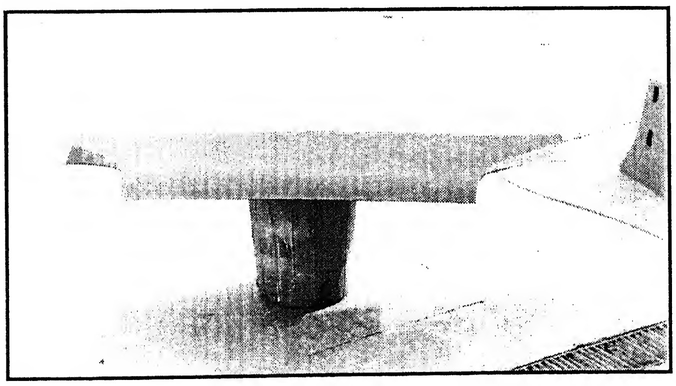


Fig 3.10: Primer is applied on bonnet pattern before making die.

Preparation of Mold

A split die is prepared from GFRP, using hand lay-up process. The pattern is treated with required sealers (Wax) and release agents. The gel coat is applied on one side of the pattern (Fig 3.11) and is allowed to cure. The purpose of using gel coat is to get a better finish of mold. Four layers of chopped strand mat glass fibers are applied on the cured gel coat surface. The glass fiber mats are saturated by polyester resin. After proper curing of one side mold the same process is applied on the other side.

Metal reinforcing members are provided on both sides of the mold, to impart more strength to the die, so that it can withstand the extra exerted pressure by the foam (Figs. 3.12 & 3.13). At the edges of split mold, flanges are incorporated so as to clamp the two halves of die with the help of bolts (Fig. 3.14). FRP protrusions are made to give a press fit arrangement (Figs. 3.15, 3.16 & 3.17).

Fig 3.11: Bonnet pattern after applying gel coat.

Fig 4.12: Reinforcing metal sections in the die.

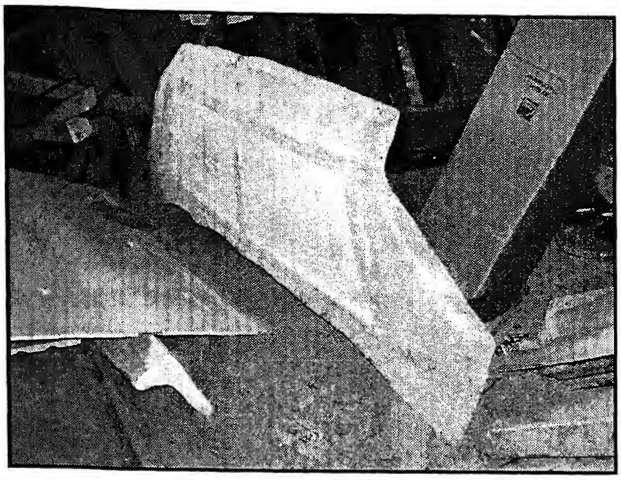


Fig 3.13: Metal inserts used in die.

Flanges are used on the periphery to make a press fit die and a nut-bolt arrangement is provided along with it, to ensure no leakage of poured foam (Figs. 3.14 to 3.17).

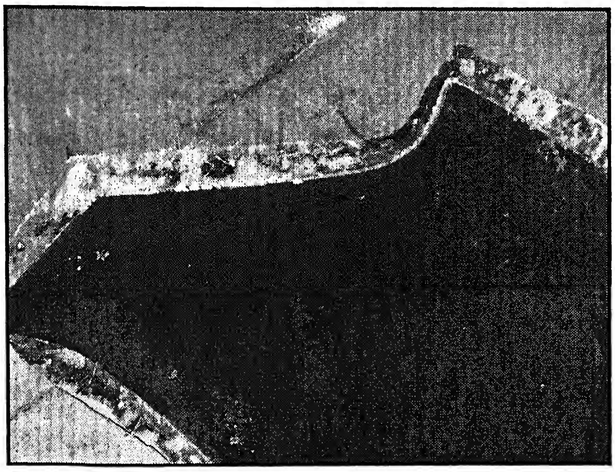


Fig 3.14: Flanges at the edges of split die.

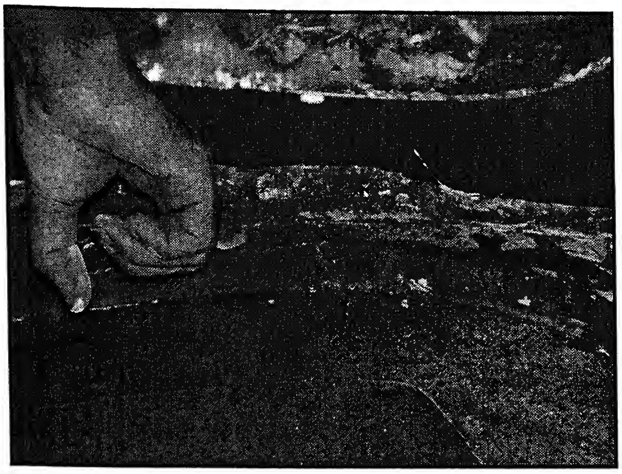


Fig 3.15: Protrusion given for press fit.

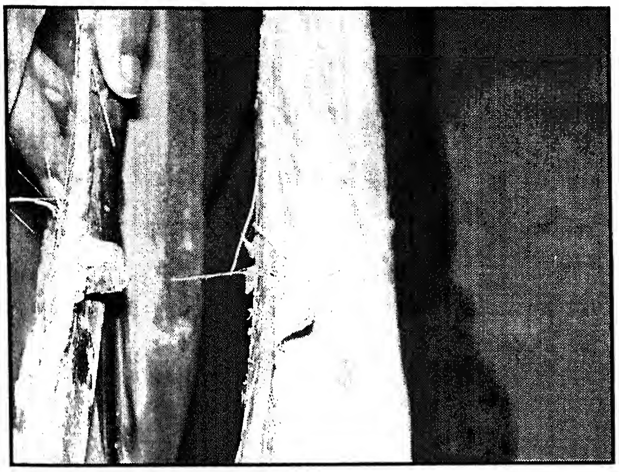


Fig 3.16: Press fitting.

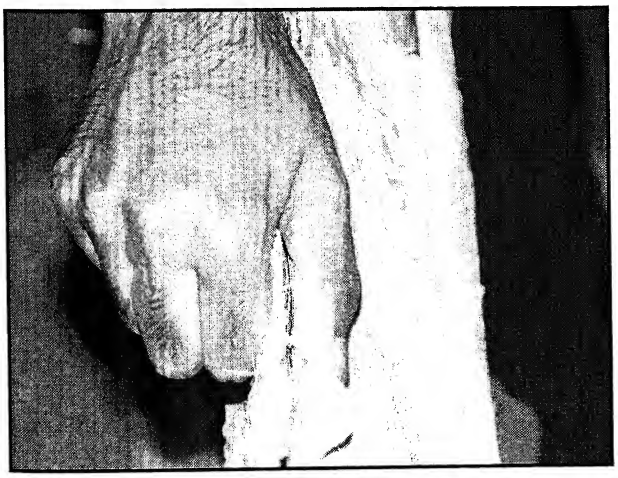


Fig 3.17: Press fitting

An appropriate cavity is created between split die for maintaining the flow of foam. Few injection points are located in case of larger panel (in case of bonnet three injection points are worked out) to make sure uniform foaming in all directions (Figs. 3.18 & 3.19).

Few holes are made for removing entrapped air from the mold when foam enters. After development of die, releasing agents and mold cleaning agents are selected as per the requirement of parts to be produced and desired surface finish (Explained subsequently in chapter 5).

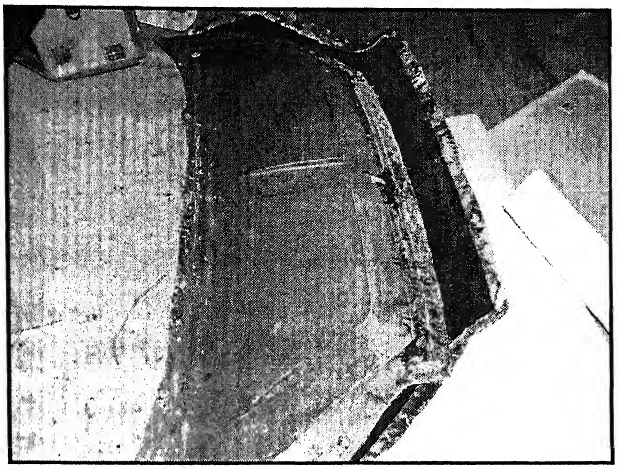


Fig 3.18: Cavity created for flow of foam.

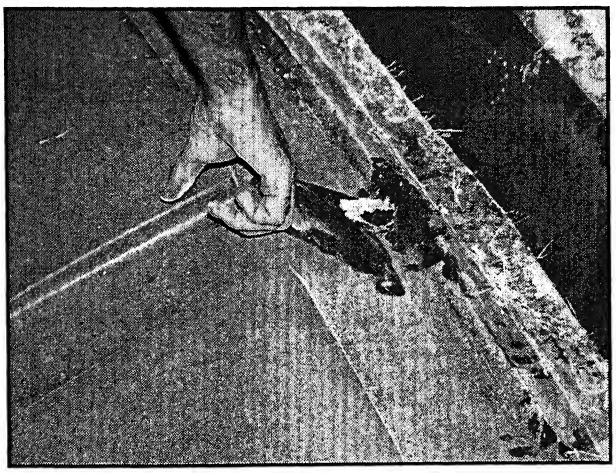


Fig 3.19: Injection point located for foam.

Preparation of Panel

Once a required mold is ready, a part of GFRP is prepared. The part can be molded using the same hand lay-up technique. The mold is treated with recommended releasing agents and then gel coat with desired color pigment is applied. In case of sandwiched panels the number of GFRP layers used is reduced, as it is used as the skin material for the component. For preparing the bonnet, only one layer of GFRP (CSM, area density=300 gms/m^2) is applied on both faces of split mold with a thicker layer on edges, and PU foam is poured from three different points. The quantity of foam to be injected is pre-calculated by determining the volume of cavity developed for sandwiching. The quantity poured is slightly more (5-10 %) than the calculated, for proper adhesion of foam with GFRP skins (as observed in test product 1, Fig 3.1). The constrained volume increases the density of foam and exerts pressure on the walls of die. Because of this reason metal inserts were incorporated in die making.

Mild steel inserts were accommodated during part fabrication for mounting of hinges and lock. In case of monocoque FRP structures these mountings create a cramping problem, which is now eliminated as additional support is provided by the foam. Figures 3.20 to 3.26 show the ready GFRP bonnet with different injection points. Bonnet is light weight and ready for installation on the vehicle.

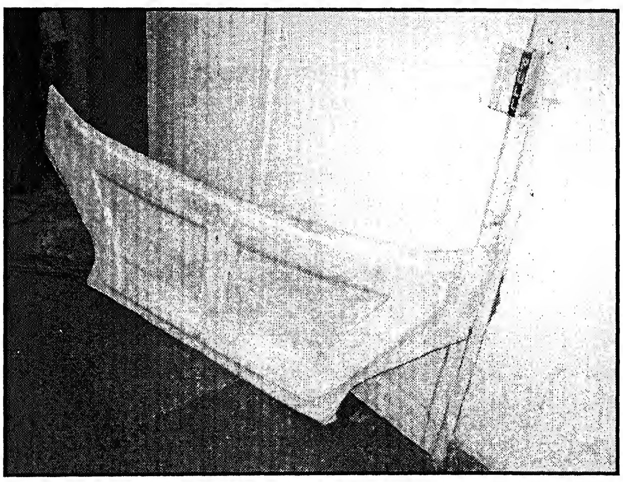


Fig 3.20: Bonnet with sandwiched construction.

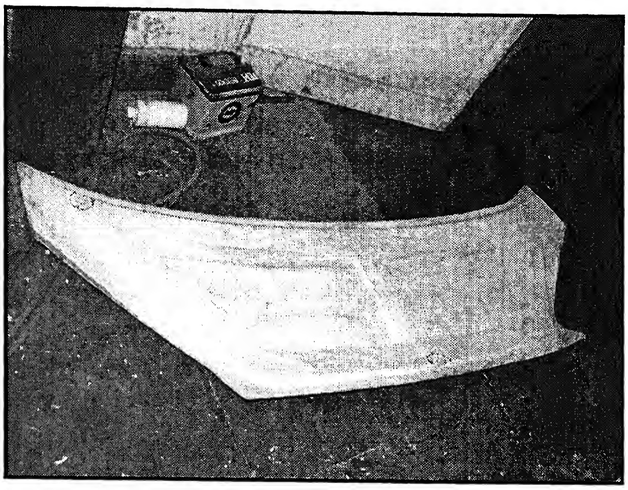


Fig 3.21: Indicating injection points.

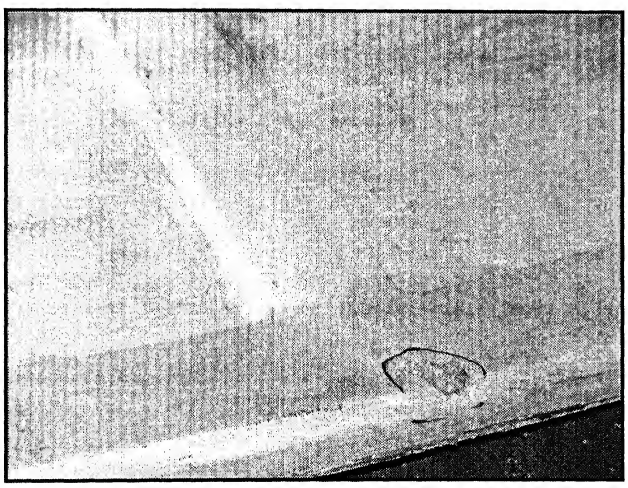


Fig 3.22: Injection point

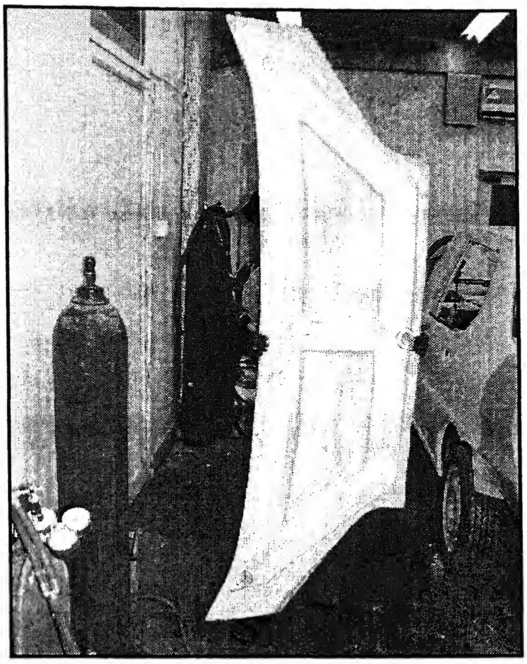


Fig 3.23: Lightweight ready bonnet.

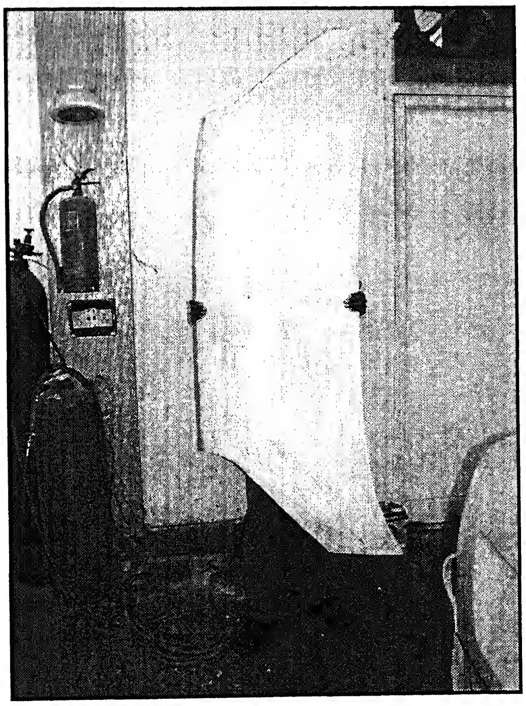


Fig 3.24: Another view of bonnet.

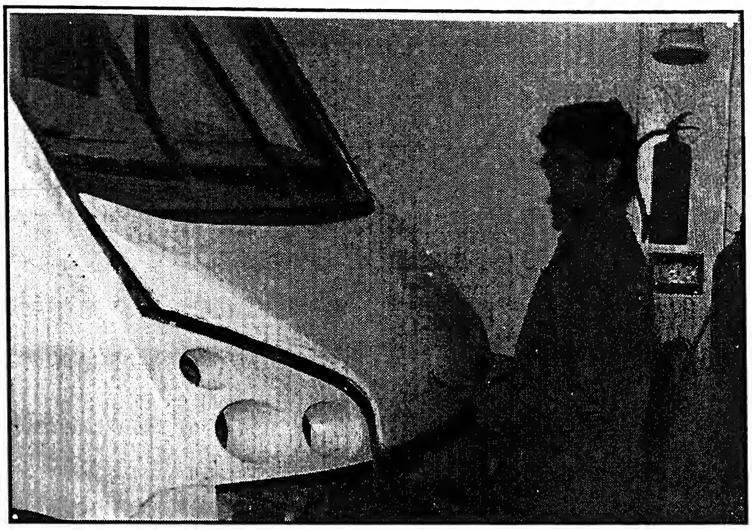


Fig 3.25: Bonnet installed on vehicle.

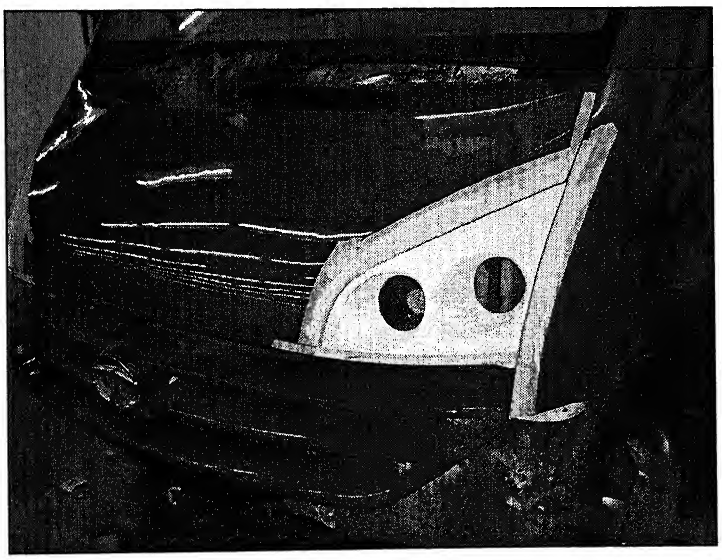


Fig 3.26: Finished bonnet

3.4 ADVANTAGES

The bonnet developed with sandwiched composite material was installed on the vehicle body; the bonnet was very well fitted on the bus and following advantages were observed:

Advantages over mild steel bonnet

The Bonnet made with sandwiched composite material was compared with existing mild steel prototype (bonnet) and following advantages were observed:

- Weight achieved of the bonnet is 9kgs. This is approximately half the weight of regular bonnet.
- Surface finish has improved reasonably.
- Filler required for finishing operation are reduced.
- Better vibration properties are achieved.
- Thermal insulation is imparted to the panel.
- Reduced production time as compared to sheet metal prototypes.

Advantages over monocoque panels

Many auto components are prepared from monocoque GFRP structures. By using sandwich structures for fabrication of automobile panels following advantages will be achieved:

- Quantity of fiber and resin used will reduce to half.
- Mounting problem of fibers will be avoided as foam gives a support for mounting.
- Better vibration properties will be achieved.
- Thermal insulation will be imparted to the panel.
- Production rate will be high in case of sandwich structures.

3.5 DEVELOPMENT OF DRIVER DOOR

As stated before, GFRP panels give the ease of fabrication for low volume production. The design and styling flexibility is also provided by the use of GFRP panels, as it has the capability of being molded into intricate shapes with a high consistency. The low tooling cost involved with FRP molds, gives the opportunity to come up with novel designs very frequently.

The second major product developed using sandwiched composites is the driver door of the same mini bus. Very similar process is applied for design and development of a driver door with sandwiched composite material. Use of foaming machine and injection of foam with appropriate pressure is recommended. The component involves many mountings, mechanisms and interface complexities. Some of them are:

- Space for the following mechanisms:
  - Winder assembly (to move the window glass)
  - RC lock (for opening the door from inside)
  - Lock
  - Outer handle
  - Locking knobs
  - Hinges mountings
  - Glass
- Weight of the door
- Strength and stiffness
- Door interface with bus body

3.5.1 Process Involved

To start the development process for the driver door, approximate dimensions of critical sections are taken and a study of critical areas like hinges, winder assembly, locks etc. is done. The driver door is more complex product to design as compared to the bonnet. Figures 3.27 to 3.30 show the approximate dimensions, different sections and profiles of the driver door.

The development of PU sandwiched GFRP door is also carried out in three major stages, same as in case of bonnet:

- Preparation of Pattern
- Preparation of Mold
- Preparation of Panel

In the present case, the pattern and split mold for the driver door is prepared. However, the component is not prepared due to the unavailability of foaming machine.

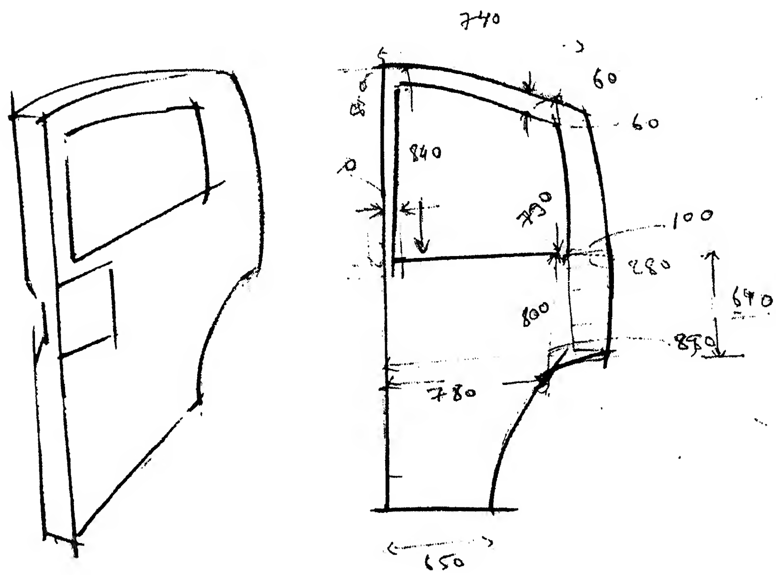


Fig 3.27: Approximate measurement of the driver door.

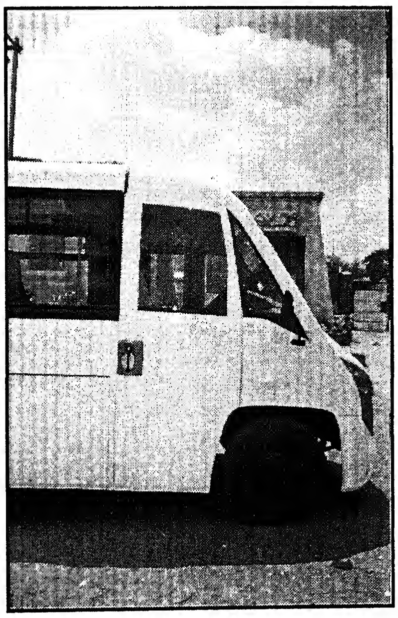


Fig 3.28: Door profile.

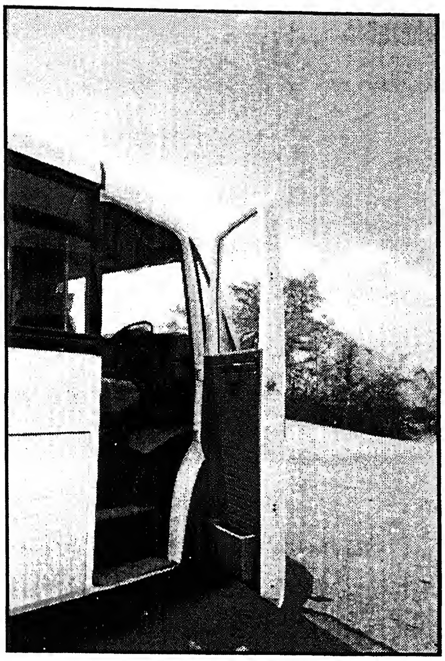


Figure 3.29: Door view with pocket.

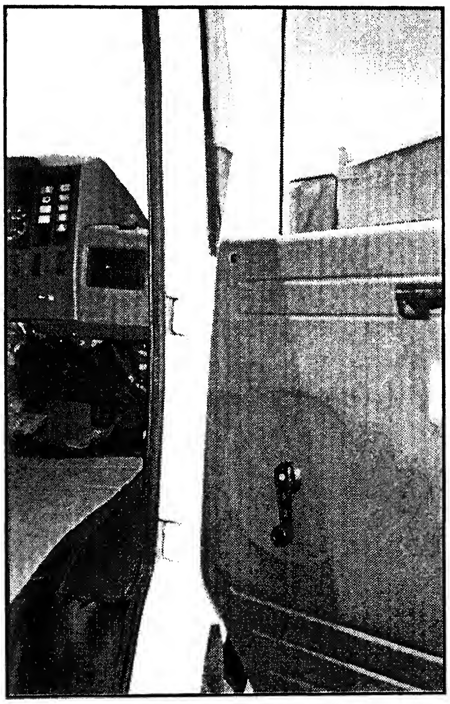


Fig 3.30: Details of hinges and winder handle.

Preparation of Pattern

A pattern of the required panel (driver door) is prepared using mild steel sheet, on the basis of section drawing done for the driver door. Proper provision is made for mounting of the hinges and interface of the door with the vehicle body. The inner skin is designed to accommodate various mechanisms of the door. The surface of the sheet metal pattern is finished to obtain an excellent mold surface.

Figures 3.33 to 3.39 illustrate the fabrication process of the pattern for the driver door. The process is followed in the following sequence:

- Creating desired space for the flow of foam, retaining the outer door profile (Fig. 3.31).
- Alignment of the door with the vehicle body. (Fig. 3.32)
- Providing space for glass and winding mechanism. Trials for the same with a dummy glass (Figs. 3.33 & 3.34).
- Preparing metal inserts for the composite door, as per the hinges provided in the vehicle. (Fig. 3.35).
- Fitting the winder mechanism in the space created. (Fig. 3.36).
- Mounting the complete pattern on the vehicle body to check the final alignment and door interface with the vehicle body. (Fig. 3.37).

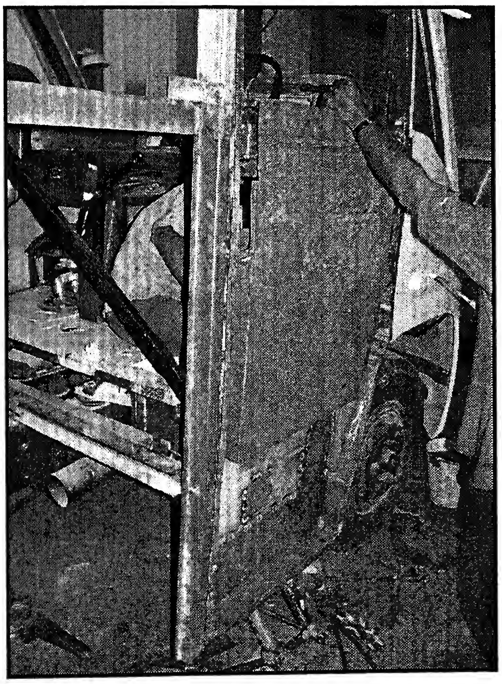


Fig 3.31: Pattern fabrication leaving space for foam flow.

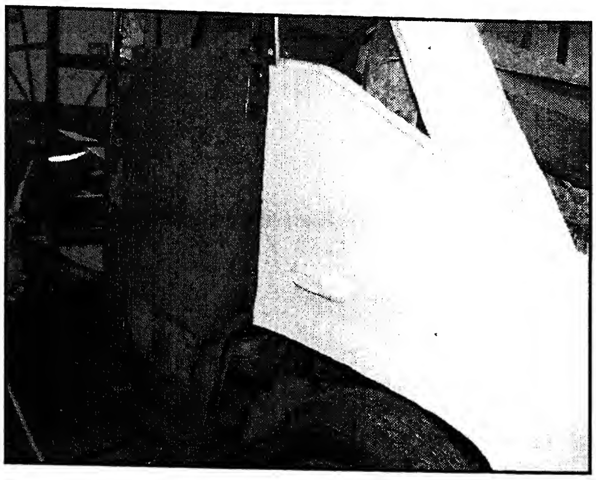


Fig 3.32: Alignment of the door with bus body

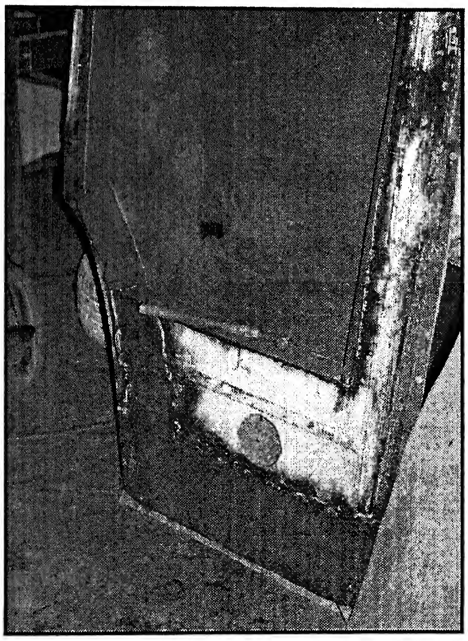


Fig 3.33 Inner side of door pattern, leaving space for glass and mechanisms.

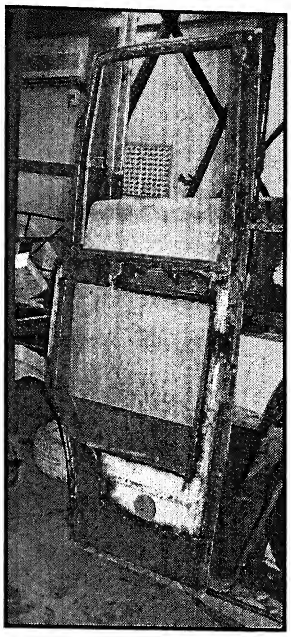


Fig 3.34: Trial with dummy glass pattern.

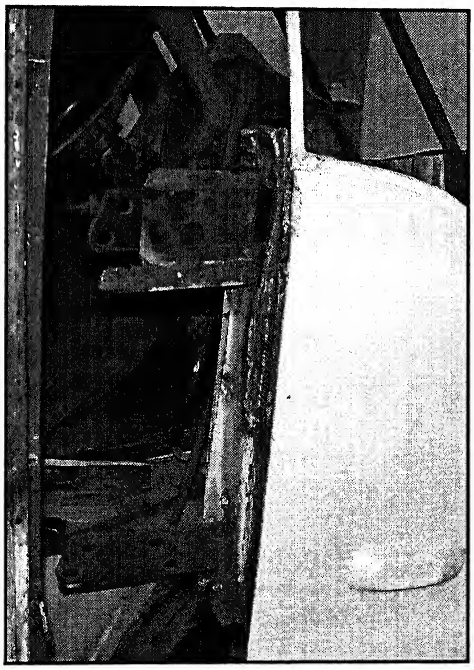


Fig 3.35: Metal inserts prepared according to hinges.

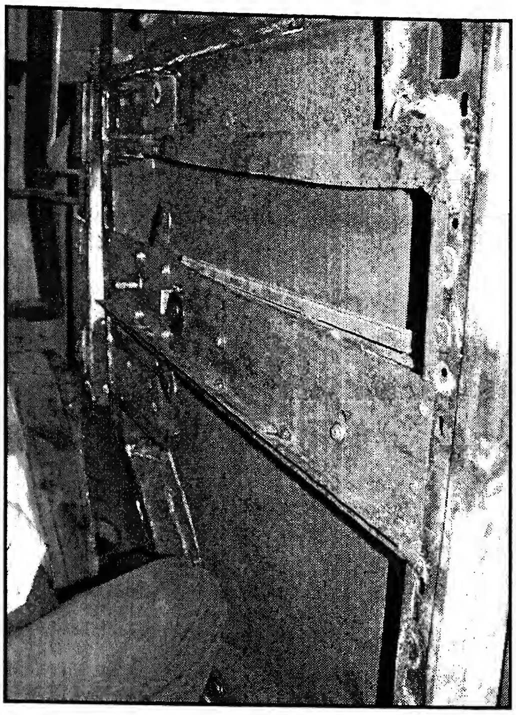


Fig 3.36: Winding mechanism fitted for glass movement.

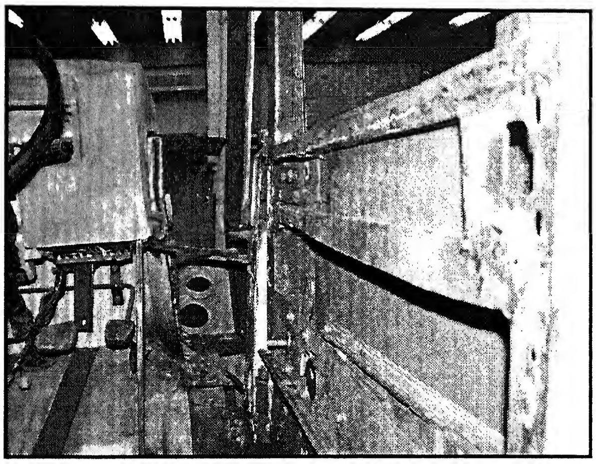


Fig 3.37: Hinges position fixed to the body.

Full finishing of the pattern is done with fillers and primer to get an excellent die.

Preparation of mold

The preparation method is same as in the case of bonnet. A split die is prepared for sandwiched driver door, four layers of GFRP (CSM with polyester resin) are used each side. Metal members were reinforced on both sides of the mold to impart strength, so that it can withstand the extra exerted pressure by the foam (Figs. 3.38 & 3.39).

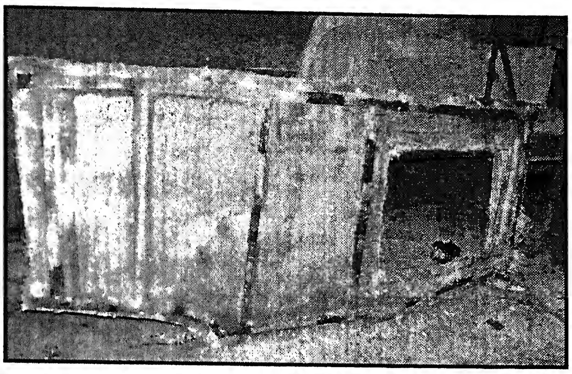


Fig 3.38: Metal inserts for imparting strength.

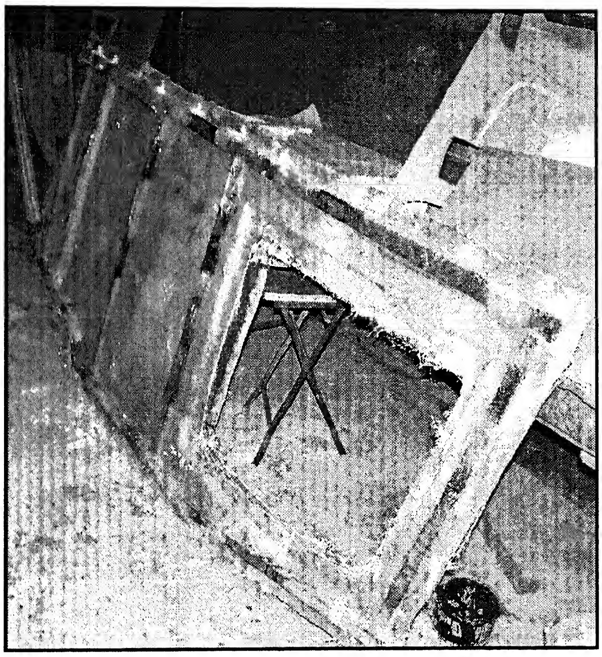


Fig 3.39: Outer skin of the die.

Flanges are used on the periphery to make a press fit die and a nut-bolt arrangement is provided with that, to ensure no leakage of poured foam (Figs. 3.40 & 3.41).

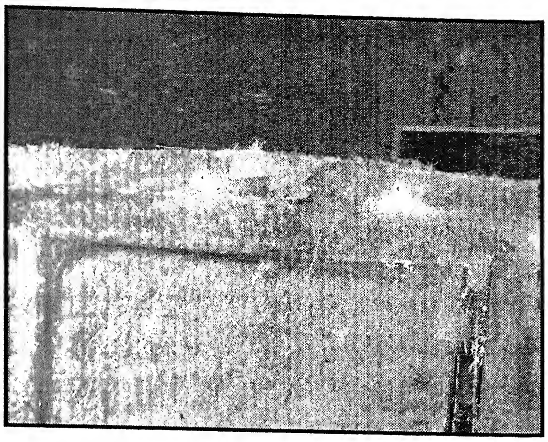


Fig 3.40: Flanges given for split die provide with holes for nut bolt system.

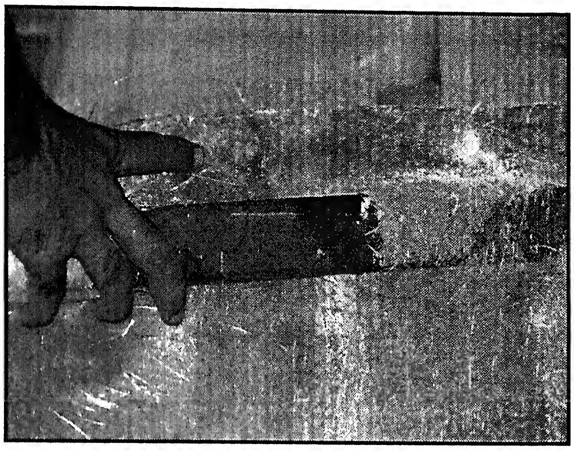


Fig 3.41: Flanges given for split die provided with protrusions for press fit.

An appropriate cavity is created between split die for maintaining the flow of foam, and few injection points are located. Few holes are made for removing entrapped air from the mould when the foam enters. Proper provisions for lock mounting inserts and hinge mountings are made in the die (Figs. 3.42, 3.43 & 3.44).

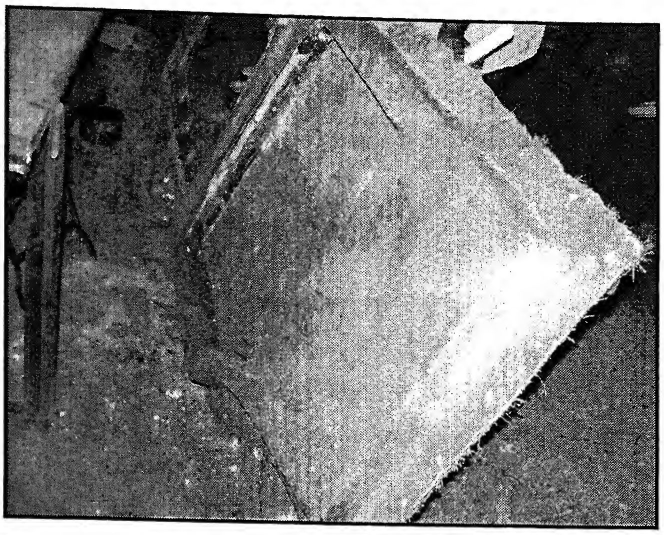


Fig 3.42: Inner side of the die creating space for accommodating mechanisms.

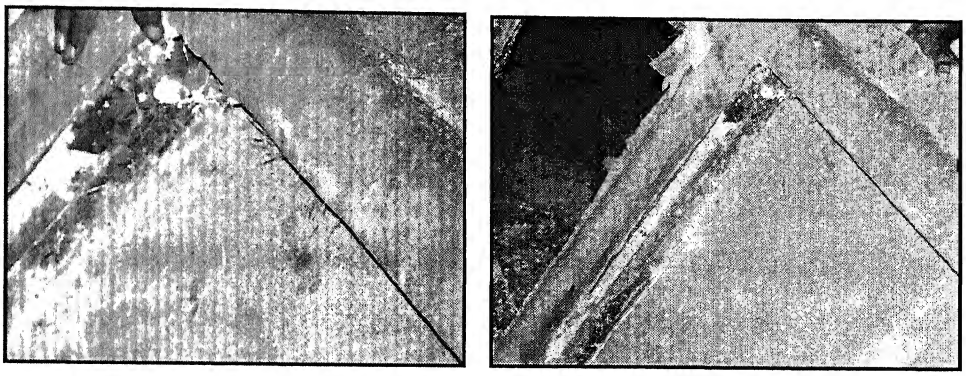


Fig 3.43: Space left for lock and glass movement.

3.6 CONCLUSION

First the drawbacks of sheet metal prototypes and monocoque structures were identified and PU sandwiched panels were recommended to overcome these shortcomings. Two test products were made using PU foam sandwich structure to develop the required skills. A bus bonnet was successfully developed and installed on the vehicle body. For the driver door of the bus, a sheet metal pattern and GFRP mold was prepared. Due to the intricate geometry of door pressurized foaming is recommended.

PU sandwiched composite panels possess better mechanical properties and are able to meet other requirements of automobile prototyping. With the help of products developed the supremacy of sandwiched construction over sheet metal prototypes and monocoque structures is established.

Chapter 4

PRODUCT DEVELOPMENT WITH FLEXIBLE CORE MAT

4.1 INTRODUCTION

As discussed in the previous chapters, FRP composites have many benefits to their selection and use. The selection of the materials depends on the performance and intended use of the product. The composite designer can tailor the performance of the end product with proper selection of materials. It is important to understand the application environment, load performance and durability requirements of the final product. Depending on the end use of the product, different constituent of a composite material can be selected.

On basis of above stated facts, few limitations of PU foam sandwiching were identified. For example, PU foam sandwiching needs proper planning and calculations before fabrication of a part. Consequently, there was a search for another core material which can meet different requirements of automobile industry. These requirements mainly includes capability of material to take thin sections, ease of manufacturing and low capital investment.

4.2 CORE MAT

Core Mats are excellent core materials developed for open molding processes of composites. The material is non woven and is available in different thicknesses as per the requirement. For production of such mats polyester based fabrics are fused at an elevated temperature and then desired cell size is produced with a stamping tool. The cell size and shape available on core mats plays an important role in flow, transfer and consumption of resin during part fabrication.

The needle shaped holes are provided on the mat for better resin transfer from one skin of GFRP to another, and thus two skins are joined with resin pillars. These pillars provide an additional strength and stiffness without creating a problem in fabrication. A comparison between core mat and PU sandwiching is done (Table 5.1) to understand the core mat advantages for specific parts and volumes.

Table 5.1: difference between PU Sandwiching and Core Mat Sandwiching

PU Sandwiching	Core Mat Sandwiching
It is a closed molding process and needs more investment in dies.	Open molding process needs normal hand lay-up investment for dies.
Foam injection machine is required for intricate shapes and proper mixing of raw constituents.	No such investment is required.
Proper planning and calculation are required for part fabrication.	Provides ease in fabrication.
Leads to loss of material in some cases.	No such process in involved.
Adhesion between two layers of GF is through PU Foam only, and may get damaged with time.	The polyester based core mats provides better adhesion, further the resin pillars formed through the needle shaped holes in mat provides additional benefit.
Fabrication of thin sections is a troublesome process.	Different thickness of core mats is available and can be used as per the requirement.

4.2.1 Flexible core mat as a sandwich material

As discussed in 3.1.1, According to the desirable properties of the end product, the desired attributes of a core material are identified. The credibility of flexible core mat as a sandwich can be established by comparing its properties with the desired attributes of a core material:

For different geometries and curvatures

Core mats are flexible mats and can be molded to any shape or curvature. Although there are some limitations of taking double curvatures, as in case of long woven glass fibers. This problem is rectified by using core mats in small pieces at double curvatures. These pieces are then butt-jointed to get a continuous surface.

Structural requirements

The core mats are made up of low density polyester based material. The structural requirement with core mat sandwich structures are met by the resin pillars formed during part fabrication. The use of these mats in super cars (as discussed in Chapter 2) is a good example of its structural capability.

Adhesion properties with laminate

Core mats have reasonably good adhesion with GFRP skins. The needle holes present on core mat surface helps in better transfer of resin from one GFRP skin to other. Also the resin pillars formed joins the two skins in a better way.

Cost and production time

Along with increased stiffness and strength, core mat also gives cost advantage. The material cost per unit volume is low as compared to monocoque GFRP structures. The resin consumption is also reduced with the use of core mats as a sandwich material. Its capability to form thick sections increases the production rate and hence labor cost is also reduced.

4.3 PRODUCT DEVELOPMENT

Few products were developed to realize the industrial advantages offered by core mat sandwich structures. The products were then compared with monocoque structures of same geometry. The part fabrication is done with hand lay-up technique and no additional equipment or mold was involved in the process.

4.3.1 Product 1- Wheel Hub

The product developed is a wheel hub for a tempo traveler. Wheel hub is an interior panel of the vehicle. To start the design process, first a wooden pattern is fabricated and then a normal hand lay-up open mold is prepared (Fig. 4.1). Required releasing agents and wax are applied on the mold surface for part fabrication. In present case wax is used as a sealer and poly vinyl alcohol (PVA) is used for releasing the part from mold.

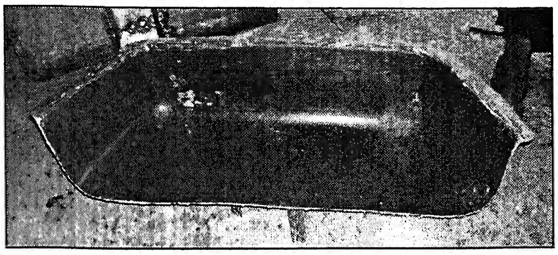


Fig 4.1: FRP mold for wheel hub

A thin layer of gel coat/matrix material is applied on the waxed mold. The gel coat is then allowed to cure (Fig. 4.2).

Fig 4.2: Applying base layer of gel coat

Short chopped strands glass fibers are sprinkled over the gel coat layer on mold surface (Fig. 4.3). The chopped fibers are sprinkled to avoid air traps in the part; this practice is more important for intricate parts. However, use of loose chopped fibers can be eliminated as core mat also helps in removing the air gaps formed, during hand lay-up.

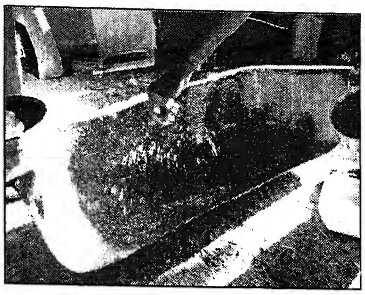


Fig 4.3: Sprinkling of chopped fibers

One layer of fiberglass (area density=450 gms/m^2) is applied on the mold surface. This layer is then saturated with polyester resin and then consolidated with the help of rollers. This layer acts as the outer skin of the final component (Fig.4.4).

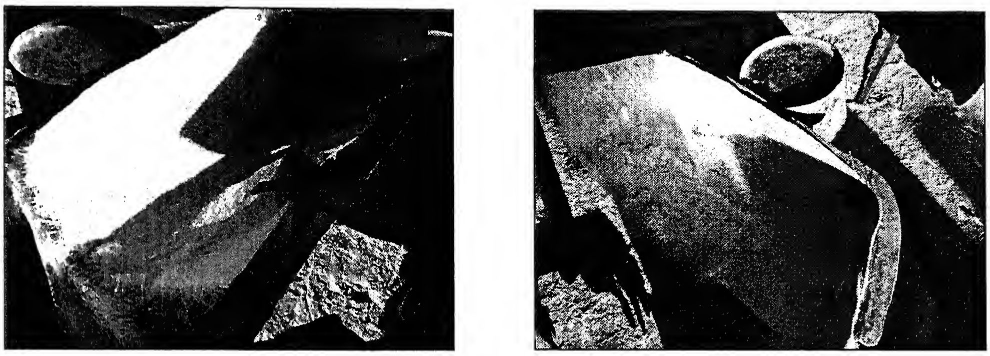
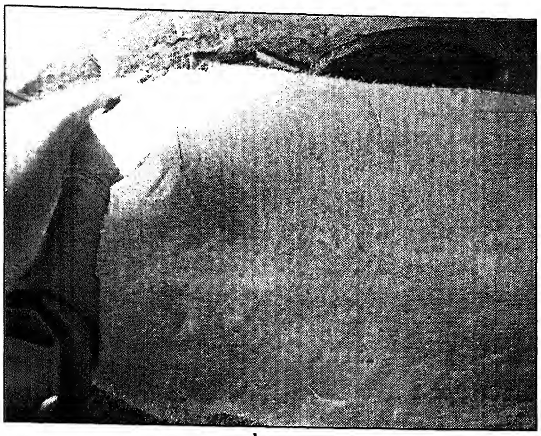


Fig 4.4: Laying and saturation of glass fibers

Core mat is placed on wet GFRP layer and is saturated with polyester resin. Resin can also be sprayed on the core mat surface (Fig. 4.5). Rollers are used for part consolidation.

a.



b.

Fig 4.5 (a, b): Laying and saturation of core mat

Pieces of Core mat should be butt-jointed rather than overlapped, to ensure a smooth surface. Since the wet Coremat will stretch, pieces can be easily jointed with a roller.
Now the final layer of fiberglass is applied in a usual way, and the same impregnation process with matrix material is repeated. (Figs. 4.6 & 4.7).

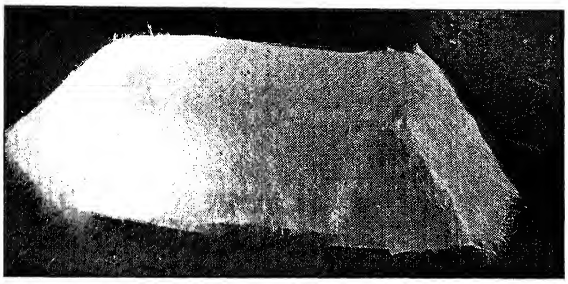
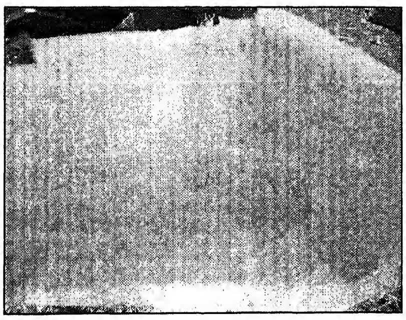
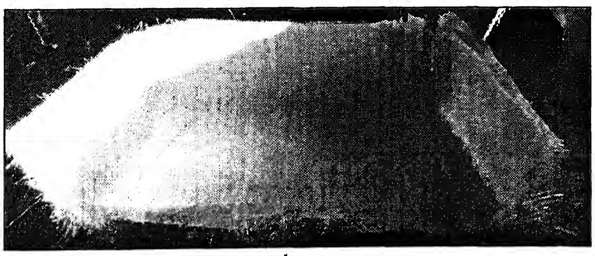


Fig 4.6: Final glass fiber layer lay-up



a.



b.

Fig 4.7 (a, b): Saturation of final layer and curing of part

After normal resin curing time the part is taken out of the mold; the part fabricated has high stiffness and better mechanical properties. Some comparisons with coremat sandwiched part and monocoque part are illustrated with the help of another product developed.

4.3.2 Product 2- Exterior body cladding

Similar process is performed for fabrication of an exterior body panel of a tempo traveler. The only difference being the use of thin layers of GFRP as a skin (area density=225 gms /m^2). The exterior claddings of the vehicle should be strong and stiff enough to withstand the impact loads. The experiment was carried out to compare the strength achieved by core mat structures with thin skins of GF.

Required wax and releasing agents are applied on the mold surface, for part fabrication. A thin layer of gel coat/matrix material is applied on the waxed mold. The gel coat is then allowed to cure. One layer of fiberglass (area density=225gms/m2) is applied over the cured gel coat surface. This layer is then saturated with polyester resin and then consolidated with the help of rollers. This layer acts as the outer skin of the final component. Core mat is then placed on wet GFRP skin and is saturated with polyester resin. Resin can also be sprayed on the core mat surface. Now the final layer of fiberglass is applied in a usual way, and the same impregnation process with matrix material is repeated (Fig. 4.8). The part is removed from the mold and edges are trimmed (Fig. 4.9).

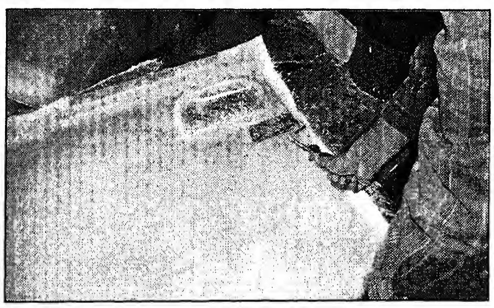
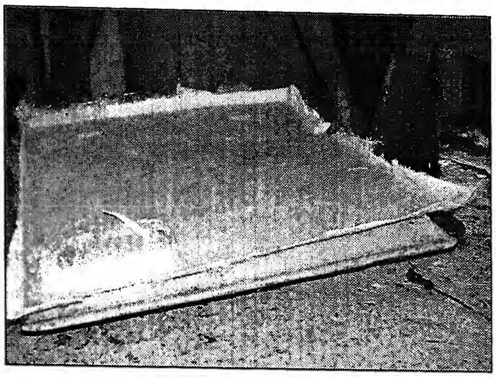
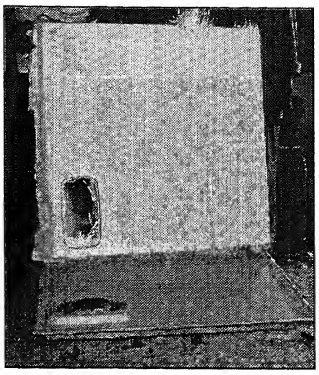


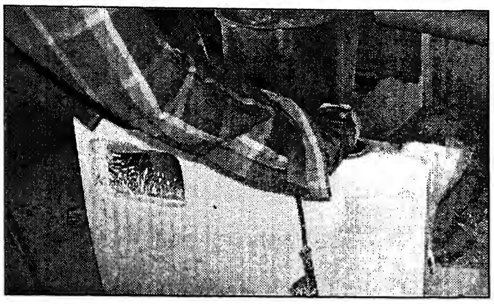
Fig 4.8: Saturation with help of roller



a.



b.



c.

Fig 4.9 (a, b, c): Part removal and edge trimming

Part is then compared with the monocoque structure prepared from the same mold (Fig. 4.10).

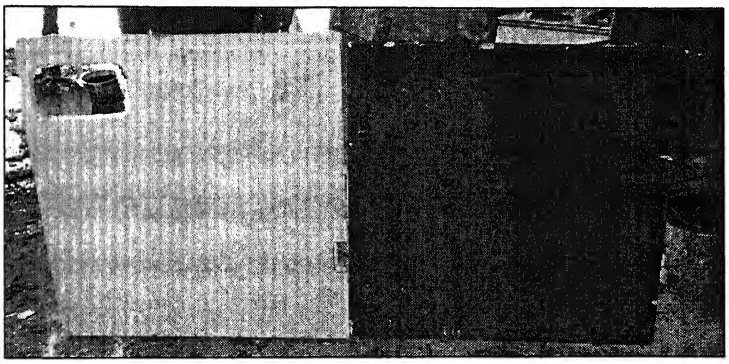


Fig 4.10 comparison of monocoque and coremat parts

The part fabricated is having high strength and stiffness. Comparing the required properties of auto panels for different applications, it is recommended to use coremat sandwich structures for exterior body panels.

Mounting problems are associated with interior panels, and some flexing of component is required to match the stiff body structure. Also the strength requirement for inner skins is much less than what we can achieve with coremat structures. The interior body panels acts as a cladding to the body structure. These can be fabricated with two layer GFRP monocoque structure.

4.4 BENEFITS

Apart from all the advantages offered by composite sandwiching, core mats provides additional benefits over other sandwich materials. Some of these benefits are:

- Resin and weight savings
- Consistent quality and thickness
- Smooth surface
- Better drapeability
- Production efficiency
- Ease of fabrication
- Low capital investment
- Capability to make thin sections and curvatures.

4.5 CONCLUSION

The use of core mat provides structural advantages and increased production rate with cost savings. The non woven coremat fabrics are available in different thicknesses; it can replace any type of monocoque structure with simple two layer GFRP sandwich structure.

As the thickness of the part increases the coremat advantage increases because moment of inertia increases considerably. Resin consumption for part fabrication is reduced. Also there is an increase in production rate as compared to monocoque structures.

Chapter 5

FINISHING OF FRP PARTS

5.1 INTRODUCTION

One major desirable property of automobile panels is finishing. The mass produced sheet metal parts are fabricated with A-class surface finish, but achieving the same quality of finish in composite parts needs careful planning. Defects like warpage, shrinkage and pin holes formation are common in composite parts.

More emphasis is given on post finishing operations of composite panels. This is done with help of heavy fillers. The use of these fillers leads to weight increment of the part. Also the time and labor involved in the process increases the total production cost.

Apart from these industrial disadvantages, the post finished parts are having poor mechanical properties due to the final skin of filler material. The surface becomes hard, brittle and any crack can easily propagate in case of impact. As a whole, the advantage of using composites for prototyping is lost and the process becomes more time consuming and costly.

Present chapter provides the solutions for the above stated problems, by illustrating an optimized process and its final product. These illustrations can be treated as an instruction guide to avoid post finishing operations in composite parts for increasing the surface finish and rate of production.

5.2 MOLD MAKING PROCESS

Mold making is one of the most critical areas of composite manufacturing. For low volume production and prototyping purpose, FRP molds are prepared to cast the final component. For relatively larger volumes machined aluminum dies are preferred. The surface quality of final component is dependent on the quality of the mold. Hence proper precautions should be taken while preparing the mold. Some of these precautions are stated below:

Finishing of Pattern

The pattern prepared, should be finished properly using fillers or some high finish material like sun mica. The finishing medium used depends on the material used for pattern making.

Post Curing

Due to prolonged polymerization reactions the mold starts changing its shape with due course of time. It is recommended to keep the mold and pattern intact for a long curing period (at least 7 days). This system is then sent for post curing at about 85°C for removal of thermal stress involved. After post curing, the problem of shrinkage and warpage of mold is minimized.

Reinforcing Members

Extra metal/concrete reinforcing members should also be given to the mold structure to increase the mold stiffness. These reinforcing members help in bearing the force exerted by pressurized foam, in case components are being made from PU sandwiching.

Mold Treatment

The mold surface is then chemically treated before part fabrication, for the purpose *semi-permanent multi release agents* may be used. These agents are applied in series to establish a mold treatment process. The process details are explained later with an example of part fabricated.

5.3 SEMI-PERMANENT RELEASE AGENTS

Conventional mold release agents like soap solutions and waxes need frequent re-spray and cause more rapid mold fouling. The operators usually tend to over spray; the excess release agent increases the scrap rates. Another consideration directly related to fast buildup is the necessity of mold cleaning frequency; short production runs and downtime add to the production costs. Reduced buildup, increased production runs, lower scrap rates and a better economy are achieved with reactive silicone resin based semi-permanent mold release agents.

These release agents bonds chemically to the mold surface and adhere strongly to the substrate, forming a semi-permanent film. This micro-thin film increases productivity in the mold by combining excellent slip with good wear resistance and high temperature stability. This way mold contamination is kept to a minimum.

This semi-permanent release film on the mold surface allows multiple part withdrawal from the same mold. The surface quality achieved can be controlled with different available grades.

The production rate of composite parts can also be increased by use of semi-permanent agents. The time and labor involved in application of conventional release agents (Wax and PVA) is much more than required for these agents. Due to its one time application the production time is dramatically reduced.

5.4 PRODUCT DEVELOPMENT- Motorbike Cowl

As mentioned earlier, the finishing operation of FRP part involves high material and labor cost. The degradation in mechanical properties and increment in weight is also caused by the use of fillers. To overcome these drawbacks precautions were taken while preparing the mold and a finished mold is then treated with a set of mold treating agents.

With the help of product developed (Motorbike Cowl) the mold treatment process is explained. The front cowl of a motorbike is a component having sharp lines and edges. The finish achieved for the part with normal fabrication process was not acceptable. A mold for the component was prepared by taking the necessary precautions and was treated with series of chemical agents in following order:

Mold cleaner: A mold cleaner is used to remove the wax and other impurities present on mold surface.

One coat of mold cleaner is applied with a 100% cotton cloth on the mold surface. The application is a wipe on - wipe off process. Wipe on the mold surface with the cleaner and wipe it off with a clean cotton cloth before it gets evaporated. After applying the mold cleaner one waits for 15-20 minutes.

The mold cleaner is applied till a clean surface is obtained. However, only one layer of mold cleaner is sufficient, once above mentioned precautions in the pattern and mold making are taken.

Mold Sealer: Conventionally wax is used as an industrial mold sealer , whereas in present case semi-permanent agents are used which forms thin invisible layers on mold surface and avoids the problems of pin hole formation in the final product.

The mold sealer is applied after the mold cleaning process is completed, in the very same fashion but with a new set of cotton cloth. One should wait for about an hour after mould sealer is applied.

Mold Release Agent: Conventionally wax or Poly Vinyl Alcohol (PVA) are used for mold release. The semi-permanent mold release agents give better and desired surface finish (matte/gloss). These agents are available in different grades and for different resin systems.

Four coats of the releasing agent are applied at intervals of 15 minutes each. One should wait at least for 30 minutes after last coat, before applying the gel coat. Figures 5.1 & 5.2 show the finished mold and the final product respectively.

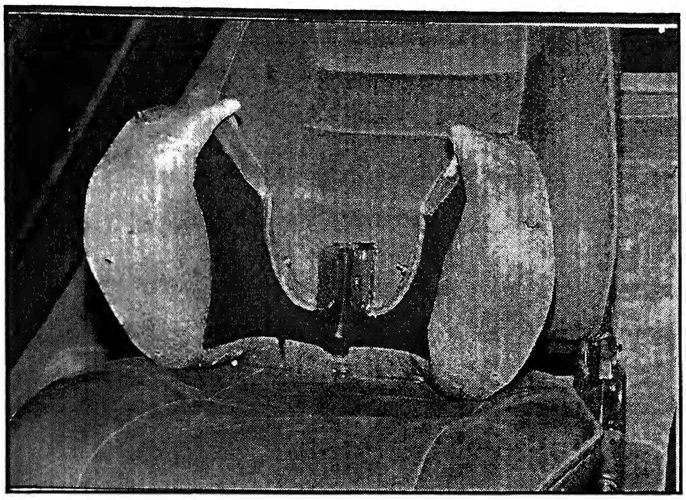


Fig. 5.1: Bike cowl mold, after completing the treatment

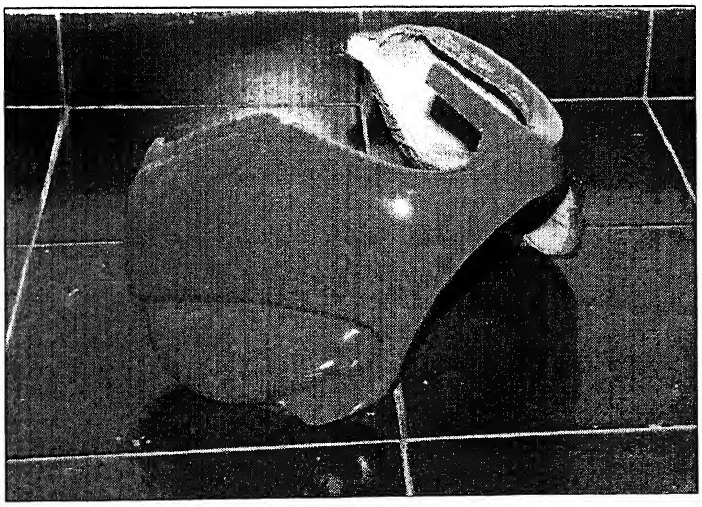


Fig. 5.2: Finished product, the bike Cowl

5.5 BENEFITS

With use of semi-permanent multi release agents, many industrial advantages are achieved. Few of them are:

Multi releases

Once treated with semi-permanent mold cleaners and release agents, the mold can produce multiple parts (15-20) without applying any other medium for mold release.

Better surface finish

With use of semi-permanent mold sealers the problem of pin holes is eliminated; taking care of the defects at micro level. It is important to note that, the proper curing and post curing operations, recommended for the mold, are very useful to avoid the extra finishing operations.

Different grades of finish

Different desired grades of finish can be achieved by using these agents and the grades may also vary with the resin systems, used for part fabrication.

High production rate

The labor and time involved in application of conventional materials (Wax and PVA) is much more than required for the semi-permanent release agents. Due to its one time application the production time is dramatically reduced.

Some other examples of panels fabricated using the same process, are discussed in next two sections.

5.6 PRODUCT DEVELOPMENT- Interior panel for Tempo Traveler

In the previous section, mold treatment process was established for a small and curved component, whereas the finishing defects and deflections are more prominent in large and flat surfaces. Another component was fabricated to prove the usefulness of the process for such surfaces. The component developed is an interior side panel for a tempo traveler (Fig. 5.3-5.5).

The panel is having large flat surfaces with many sharp contours and undercuts, which creates the problem in part withdrawal. The mold is treated in the very same fashion as discussed for a motorbike cowl. Figures 5.3 & 5.4 show the mirror finished mold and the final fabricated part respectively.

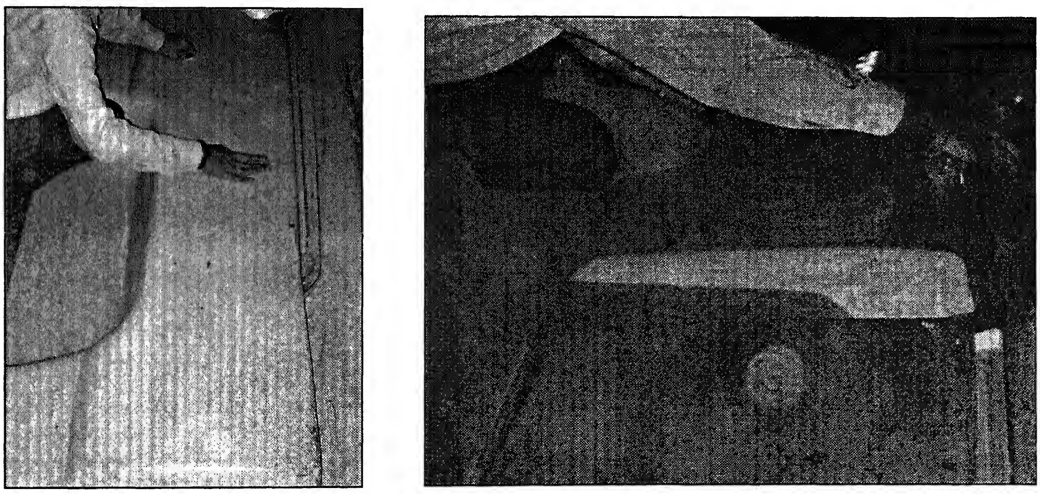


Fig 5.3: Mold is treated to obtain a mirror finished surface

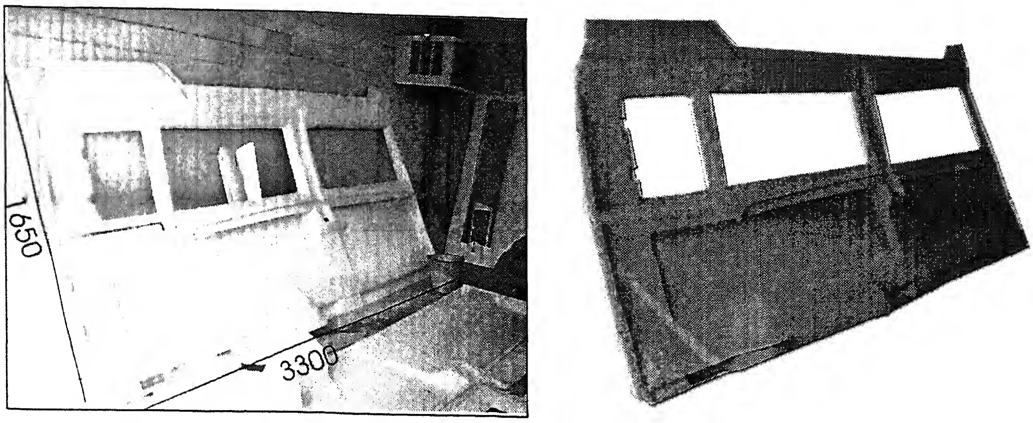


Fig. 5.4: Final part obtained from the mold

Figure 5.5 shows the painted and installed side panels for an "office on wheels", developed on a tempo traveler at DC Design, Mumbai.

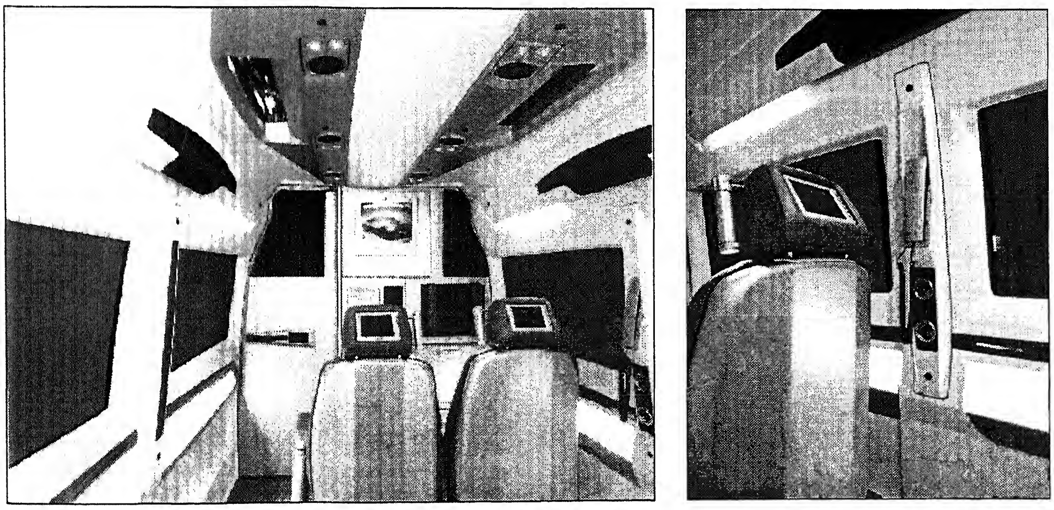


Fig 5.5: Tempo Traveler interior panels

5.7 PRODUCT DEVELOPMENT – Car Fender

With the development of a motorbike cowl and an interior panel, an optimized process for obtaining finished FRP parts is established. In the present case a car front fender is

Two prototypes of the front fender were made (Figs. 5.8 to 5.11) by following the procedure discussed above. The hand lay-up technique was used for part fabrication. The panels were weighed before and after painting to check the weight increment after finishing.

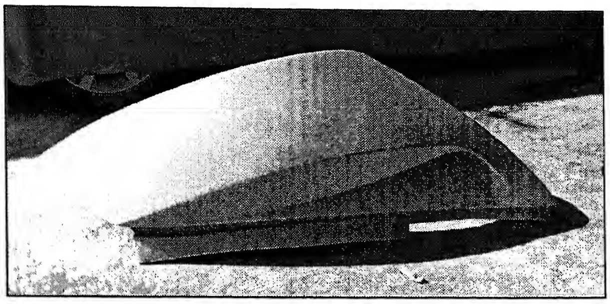


Fig 5.8: Molded part, with two layers of CSM glass fiber; it weighs 3.5 kg before painting.

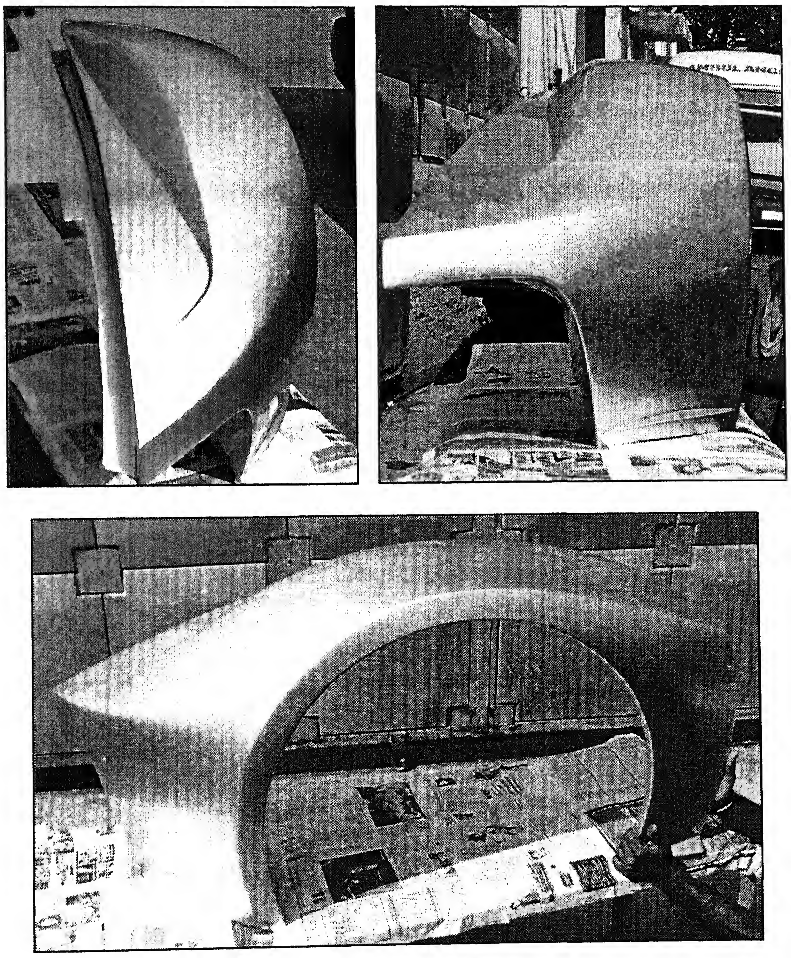


Fig. 5.9: Painted fender; weighs 3.85 kg after painting.

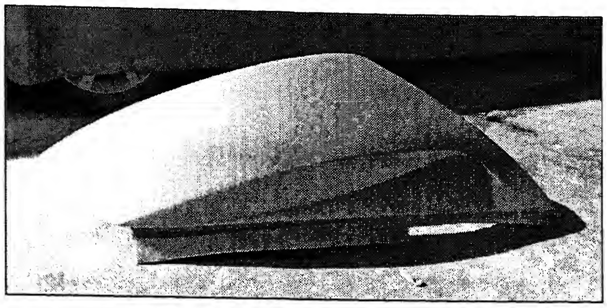


Fig. 5.10: Molded part, with three layers of CSM glass fiber; it weighs 5.3 kg before painting.

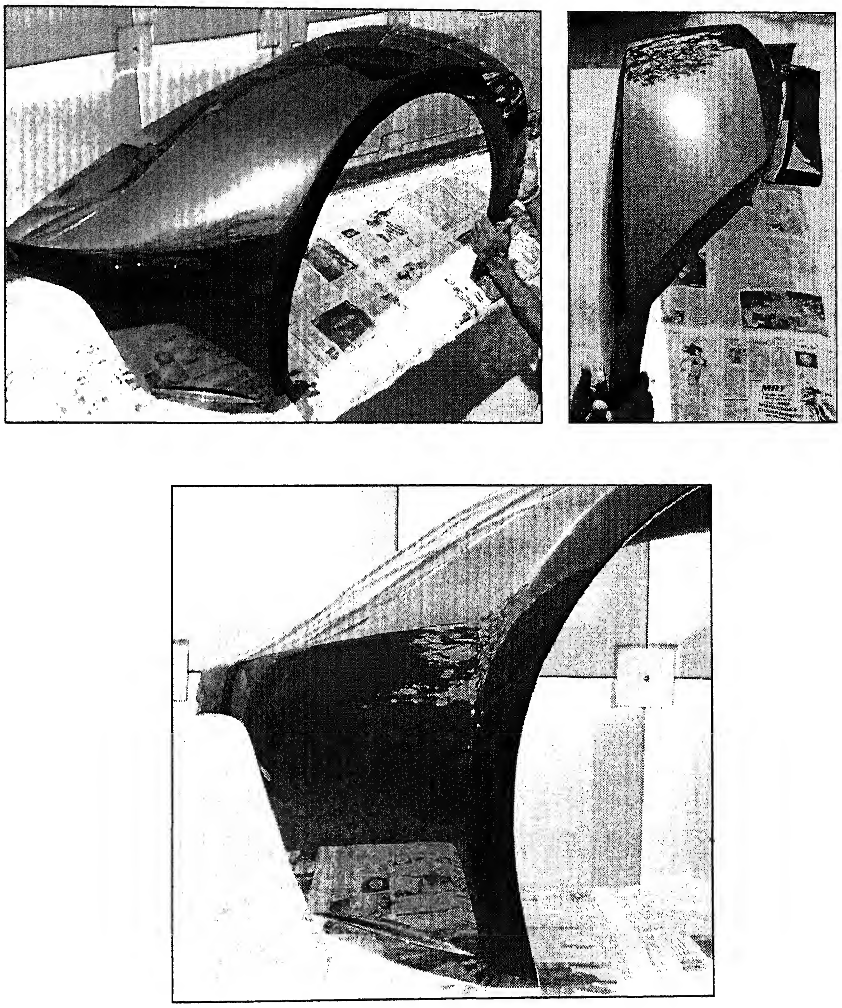


Fig. 5.11: Painted fender; weighs 5.6 kg after painting.

The panels were developed in favor of DC Design, Mumbai. The sheet metal fabrication and finishing was done at Mumbai. FRP mold preparation and part fabrication were done

at KG Fibers, Pune. The final fender after installation can be visualized with the help of Figure 5.12.

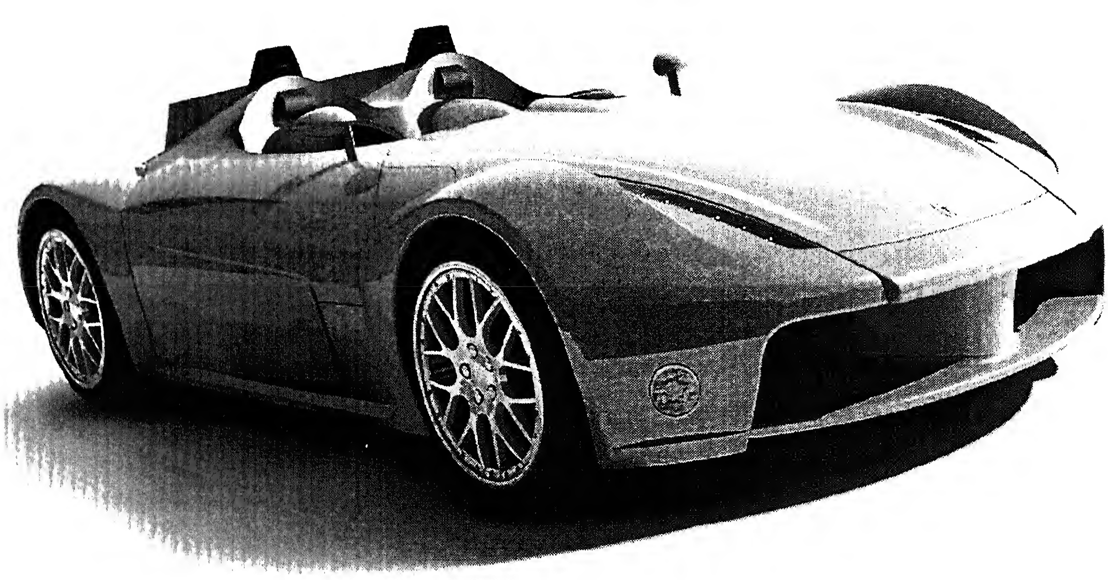


Fig 5.12: The final fender after installation

5.8 CONCLUSION

The problems related to finishing of FRP parts were identified and solutions were given to minimize these problems. With the help of the prototypes developed, an optimized process of fabrication of FRP parts is established. The precautions taken during mold preparation minimize the finishing operations of FRP parts.

Chapter 6

RESIN INFUSION MOLDING

6.1 INTRODUCTION

In previous chapters, fabrication of sandwiched composite panels with hand lay-up technique was discussed. Hand lay-up is most conventional composite manufacturing technique. It is more prevalent in countries like India where labor intensive process are encouraged.

Like any other process, hand lay-up is having many drawbacks and limitations; some of them are:

- Air void formation in parts

Entrapment of air voids in FRP parts is a very common problem, which makes the part localy weak.

- Low fiber volume fraction

In a composite panel, reinforcement (fibers) provides most of the strength and the matrix material (resin) takes the responsibility of providing required rigidity. In processes like hand lay-up the glass fiber volume fraction is generally in the range of 25-35 %, which needs extra layers of reinforcements for getting desired strength of the panel. The fiber volume fraction is preferred to be greater than 50%.

- Styrene emission

Being an open molding process, styrene emission from polyester resin pollutes the air.

- Consistency of parts

Although the shape consistency is very much achieved in hand lay-up process, the product quality (weight, air entrapment, surface finish etc.) may vary considerably depending upon the skills of worker.

To avoid these problems many techniques are developed. Vacuum bagging using an autoclave has been most popular mostly with aerospace industries. This process enhances fiber volume fraction and reduces styrene emission. Pre-impregnated sheets (prepregs) are usually used in this process, which requires curing of the product at elevated temperatures.

Recently a simpler and effective technique, Vacuum Assisted Resin Infusion Molding (VARIM) has been developed. It is also known as Resin Infusion Molding (RIM) or vacuum infusion process (VIP).

Vacuum infusion is a variation of vacuum bagging process where a dry perform of fiber is placed within the vacuum bag. The resin is introduced into the mold after the vacuum has pulled the bag (in this case a thin film) down and compacts the laminate. The vacuum acts as a driving force for pulling the liquid resin from a reservoir to the dry perform and wetting its fibers.

Vacuum infusion process can be considered as a closed mold system, which means the fiber preform is sealed prior to and during lamination. Since no room is provided for excess resin flow, this process can achieve 70% reinforcement content.

As the name suggests, sometimes a general confusion occurs between VARIM and Vacuum Assisted Resin Transfer Molding (VARTM).This can be distinguished with a simple fact that in VARTM the resin is forced into a closed mold with external pressure, where as in VARIM the resin is sucked into a closed mold by creating negative pressure inside the mold.

6.2 PROCESS DESCRIPTION

To make a vacuum infused composite, dry preform (part) is placed on the mold surface as shown in Figure. 6.1. Core material is placed in between two glass fiber skins, if sandwiched structure is required. A perforated release film is placed over the dry perform and a perforated tubing is positioned as a manifold to create vacuum in the preform. Now the laminate is sealed with a soft vacuum bag (Figs. 6.1-6.3).

Vacuum is applied into the cavity to evacuate the air and compress the dry preform. The seal is verified and finally resin is allowed into the cavity to wet the preform. When the resin is pulled into the mold the reinforcement is already compacted, therefore there is no room for excess resin. Vacuum pressure remains on the laminate during the curing cycle to have high fiber volume fraction. The level of vacuum controls the thickness of the laminate.

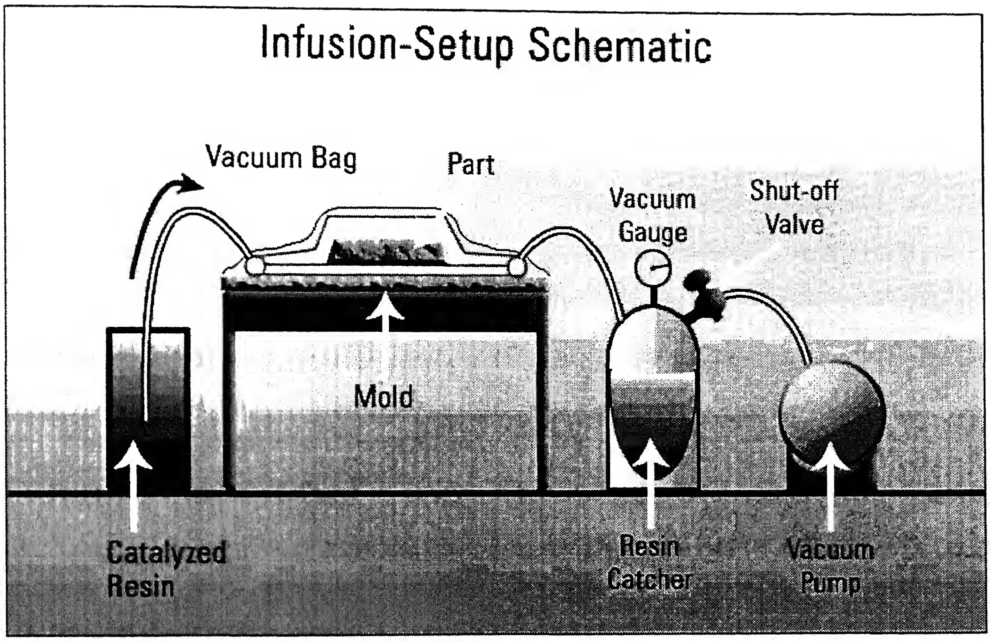


Fig 6.1: Schematic diagram, Vacuum Infusion- setup

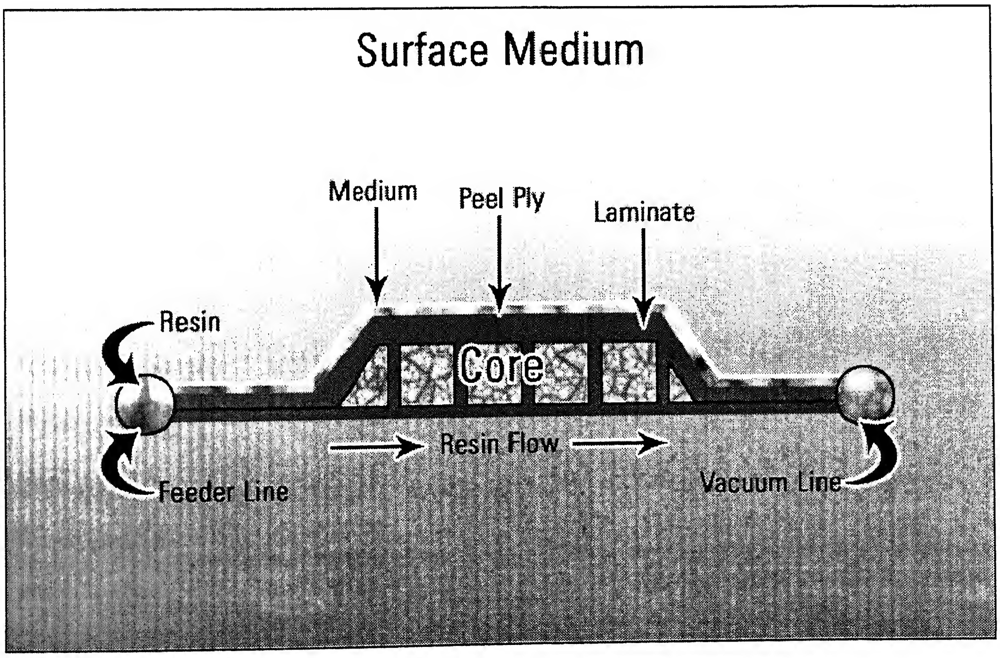


Fig 6.2: Surface medium

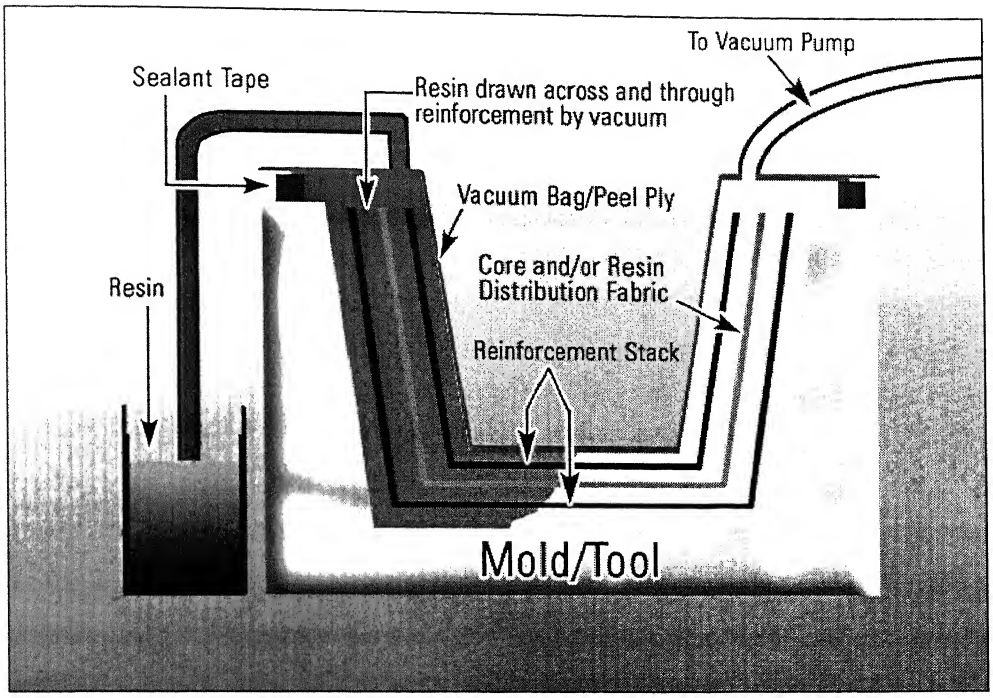


Fig 6.3: Resin flow pattern

6.2.1 Tools and equipments required

Stated below are the major tools and consumables required for setting up RIM process, each equipment is having its own significance and can be used as per the product requirement. The equipment purposes are explained in RIM set-up description.

- Resin flow tubes
- Vacuum flow line
- Spiral tubes (for resin flow/for vacuum line)
- Resin flow regulator
- Vacuum pump
- Vacuum bag
- Peel ply
- Flow media
- Filter jacket
- T- fittings
- Double sided sealant tapes

6.3 RIM SET-UP

Like any other composite manufacturing process a pattern is required to prepare a mold. However, the mold and component preparation for RIM are different and requires certain materials which are unique for this process. The complete RIM Set-up process can be carried out under the following steps:

6.3.1 Preparation of Mold

Like any lamination process, a good quality single mold is required for vacuum infusion. The mold should be rigid and have a high-gloss finish. Ideally, this mold will have flange of at least 6 inches to be used for the placement of sealant tape and spiral tubing. RIM molds does not require any special type of releasing agents, any conventional material can be used for the purpose.

6.3.2 Preparation of Component

The preparation of component in RIM requires certain materials which are unique for this process. The selection of these materials depends on the desired features of the end product.

Selection of reinforcement

Selecting reinforcement is an important decision for any laminate, but there are additional considerations when choosing one for infusion. While all fabrics will potentially infuse, different materials and weave styles can severely alter resin flow rates.

Fiberglass is the most frequently used reinforcement in vacuum infusion. Most fiberglass fabrics offer high permeability, allowing resin to easily flow through. In general, looser weaves tend to infuse better, as there is less crimping of strands.
When using a non-woven mat, continuous strand mat will offer superior infusion over a chopped strand.

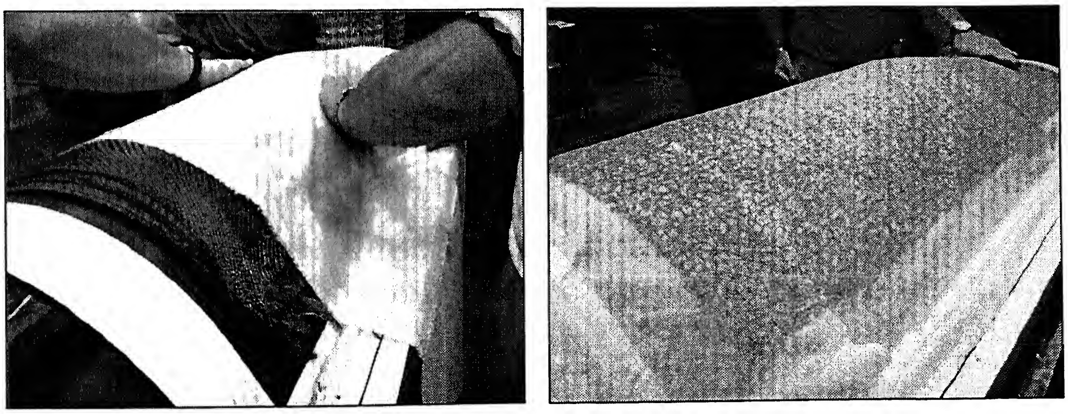
Carbon Fiber (Graphite) and **Kevlar** reinforcements can also be used in vacuum infusion, though they tend to infuse more slowly.

Selection of flow media and/or core material

A concept unique to vacuum infusion is the idea of flow media. In RIM, resin enters the laminate at a fixed point (or points) and must be directed. Resin will always travel in the path of least resistance. Unfortunately, many reinforcements can provide a great deal of resistance that can prevent resin flow. Aiding the flow of resin is the job of flow media.

The flow media is typically laid as a single layer between or above the layers of reinforcement to provide an easy flow conduit for resin. This material can also become part of the laminate. Flow media comes in several styles.

• **EnkaFusion Nylon Matting** provides the fastest infusion times. Constructed of randomly oriented, entangled nylon filaments, this matting can typically move resin at high flow rates (Fig. 6.4(b)).



a. b.

Fig 6.4 (a.) Peel Ply (b.) EnkaFusion Nylon Matting

• **Soric XF** provides maximum conformability. This material is used as both a core and flow media. It has hexagonal flow channels that quickly move resin throughout the laminate, while simultaneously adding thickness. Laminates incorporating Soric can typically experience 35% less resin retention than all glass laminates. Though used as a core; Soric does not provide any significant structural properties (Fig.6.5).

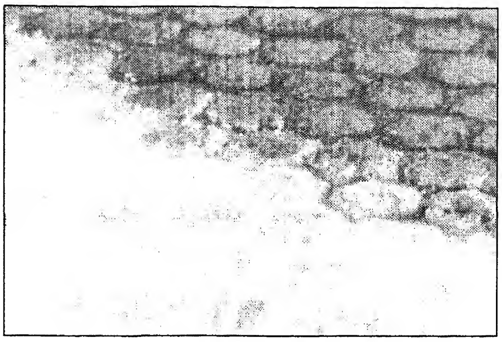


Fig. 6.5: Flow media, Soric XF

• **Structural Sandwich Core** serves as both a flow media and structural core. This material is similar to traditional vinyl foam cores, but includes grooves, perforations, and scores in the core material to help resin traverse the laminate while simultaneously adding strength and rigidity. Additionally, this material is on a scrim backing to aid conformability. (Traditional, closed-cell cores are not recommended as they tend to pool resin rather than aid its flow). (Fig. 6.6)

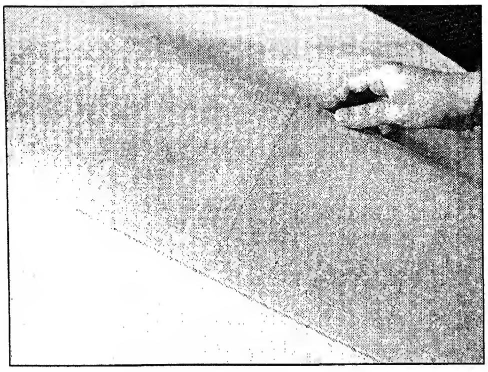


Fig. 6.6: Structural sandwich core

Selection and installation of resin feed lines

Resin will be fed from a standing source. The line for getting the resin into the laminate will have to be installed before closing the bag. Although the same tubing that is used for applying vacuum is fine for getting the resin to the bag, after the resin is being directed through the laminate there are some materials unique to RIM which can help direct the resin flow.

• **EnkaFusion Filter Jacket** is used in nearly all RIM projects. This material is used on top of the laminate and removed from the laminate when pulling the part from the mold. It also provides the removable material which is used for anchoring the T-

fittings which connects the resin and vacuum lines. The jacket holds resin until the entire length is filled. At that point, resin begins to flow outward into the laminate, providing consistent flow rates across a long span. This style of EnkaFusion is particularly useful for resin feed lines (Fig.6.7).

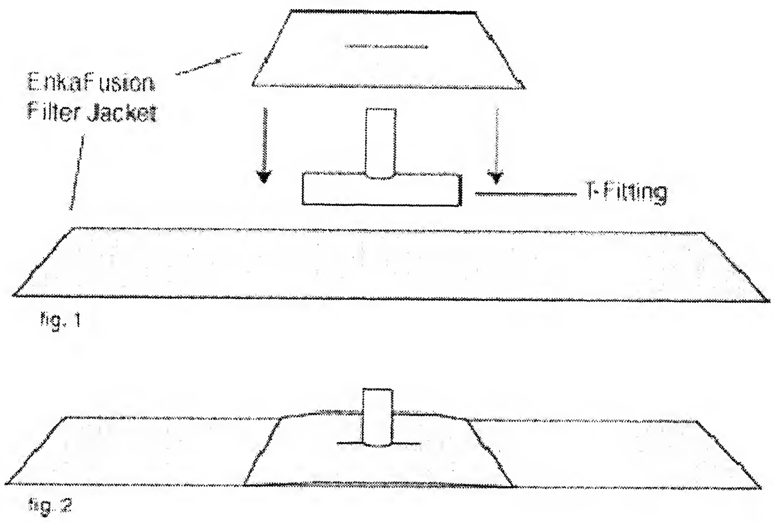


Fig. 6.7: EnkaFusion filter jacket arrangement

• **Spiral tubing** is a plastic ribbon that is coiled into a tube shape. Due to its construction, air or resin can enter or leave the walls of the tube throughout its length. This property makes spiral tubing ideal for in-bag vacuum lines or resin feed lines. When used as a feed line, resin quickly travels through the tube, but simultaneously seep out along the way. This allows quick wet-out of a long stretch within the laminate. For the same purpose, omega tubes (Fig. 6.8) can also be incorporated.

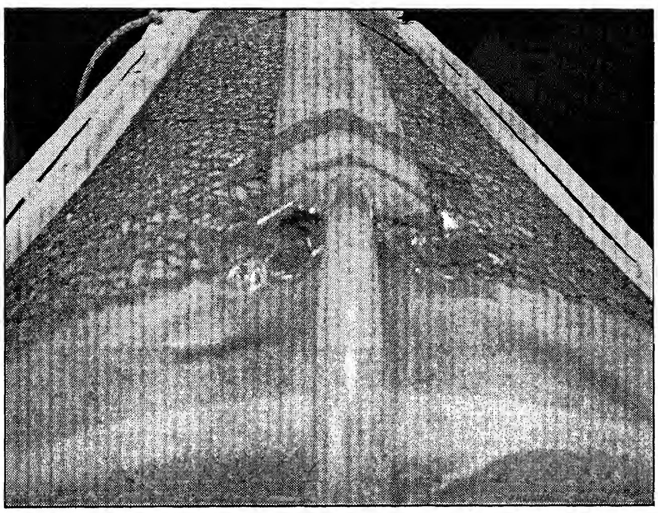


Fig. 6.8: Spiral tubing or omega tube can be used for resin feed lines

Selection and installation of vacuum lines

In RIM, the vacuum lines are extended within the sealed bag. Spiral tubing is ideal for this purpose. In order to achieve complete infusion, resin must be pulled to all corners of the laminate. Because the standard set-up infuses into the center of the laminate, spiral tubing would usually be placed around the flange. (Fig. 6.9)

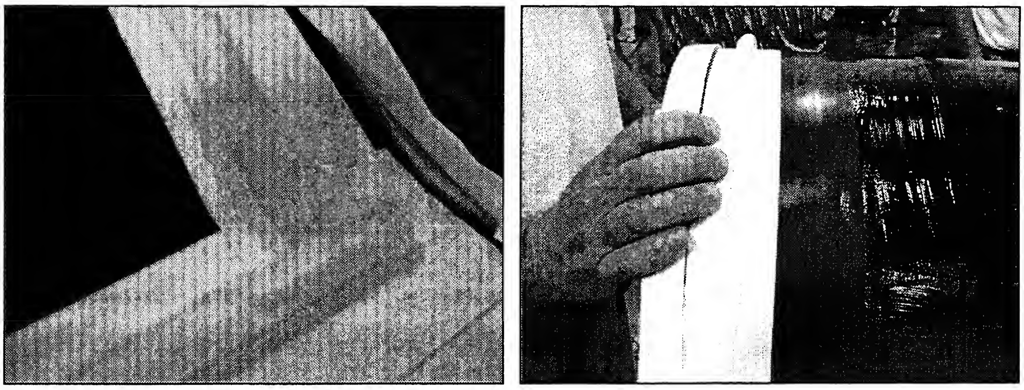


Fig. 6.9: Vacuum line installation

Applying vacuum bag

The vacuum bag is built after placing the dry materials in place. The bag is kept tight, in a way such as it allows plenty of room for all the materials including networks of tubing. Too much or too little bag can result in resin pooling or improper infusion.

Once the bag is built, the vacuum and resin tubing in the bag are attached to their respective sources. The resin line is clamped off before starting the pump (Fig. 6.10). A resin trap is introduced in the vacuum line on the side of vacuum pump to avoid/trap the excess resin from the bag traveling towards the vacuum (Fig. 6.11).

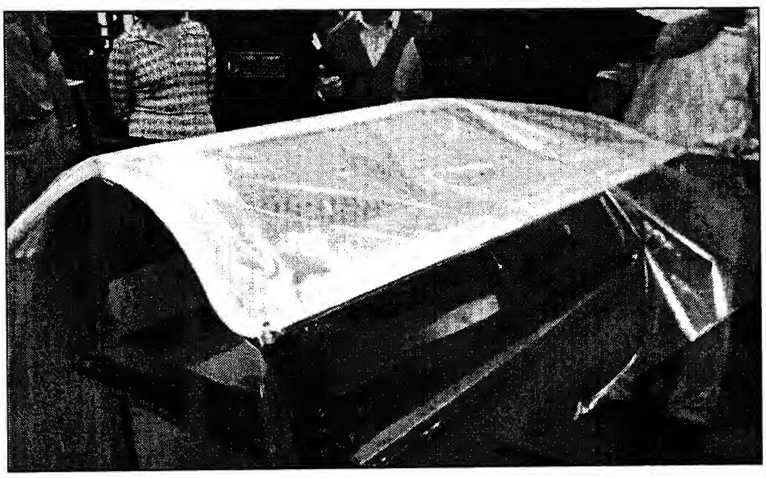


Fig. 6.10: Applying vacuum bag

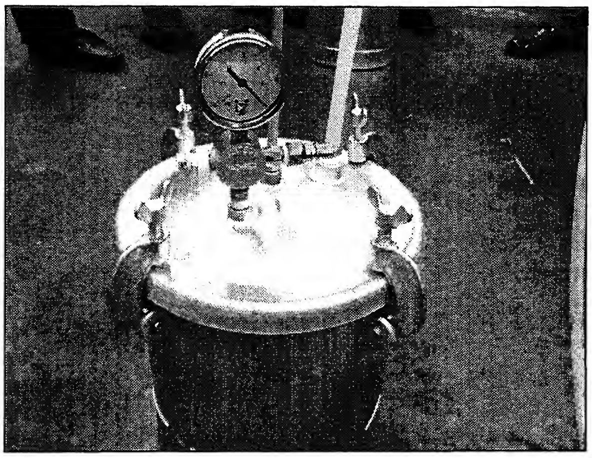


Fig. 6.11: Resin trap

The pump is attached to the bag after keeping all the dry materials in place, then dry run trials are practiced to ensure proper vacuum, leak proof bagging and placement of reinforcing materials in case of complex curvatures. To ensure proper vacuum the leaks are arrested using an ultrasonic detector, to keep the budget low a simple stethoscope can also be used.

Selection of resin

Resin choice is another key aspect of RIM. Any resin can be used for infusion, though there are some general guidelines that are considered when making a decision. One important piece of information that should be examined is the resin viscosity.
Typically, lower viscosity will aid infusion, as it allows easier permeation of the reinforcement. This is not to say that higher viscosity resins will not work, but they may require more careful planning, more resin lines, and more flow media.

Infusing Catalyzed resin

Once everything is in place and ready to go, the resin is catalyzed. The stability of resin bucket and tube placement is checked, once this is satisfactory, the flow regulator is removed to unclamp the resin inlet. Quickly resin is sucked through the tube into the vacuum bag impregnating the dry reinforcement through flow media.

Once resin reaches the laminate, the resin feed line quickly fills up. Once full, the resin begins to expand outward into the reinforcement. The rate of infusion depends upon many variables, but the resin should be visibly moving. The phenomena is allowed to continue until the entire laminate is saturated.

Once the resin line is clamped off, the infusion is complete. However, the laminate is kept with the pump running to maintain constant vacuum pressure until the resin has sufficiently gelled. Otherwise, air could be introduced prematurely.

6.3.3 Typical Variations in RIM Set-Up

The set-up for RIM process is unique for different parts and shapes, hence to achieve the desired results the resin flow characteristic for different conditions are kept in mind. When choosing material arrangements, it is helpful to understand why resin travels the way it does. When a vacuum is pulled, all air is removed from the laminate, creating open spaces of complete vacuum. This causes pressure to be placed on the dry preform. Naturally, this pressure will want to be relieved by refilling the open spaces. In RIM, resin will provide this relief. In order to create an even resin front that will wet-out the entire laminate two important resin flow characteristics are kept in mind.

- Resin wants to fill open spaces created by the vacuum.
- Resin wants to take the path of least resistance.

Utilizing these two concepts, it is possible to manipulate resin across an entire part with as little as one resin inlet and one vacuum outlet. The trick is to place in-bag extensions of these lines in order to create a uniform resin front.

In Figure 6.12, vacuum lines are extended using spiral tubes and resin inlet is kept at the centre, as the flow media selected in this case is Soric XF which aids the flow in a uniform way diametrically out towards the vacuum line.

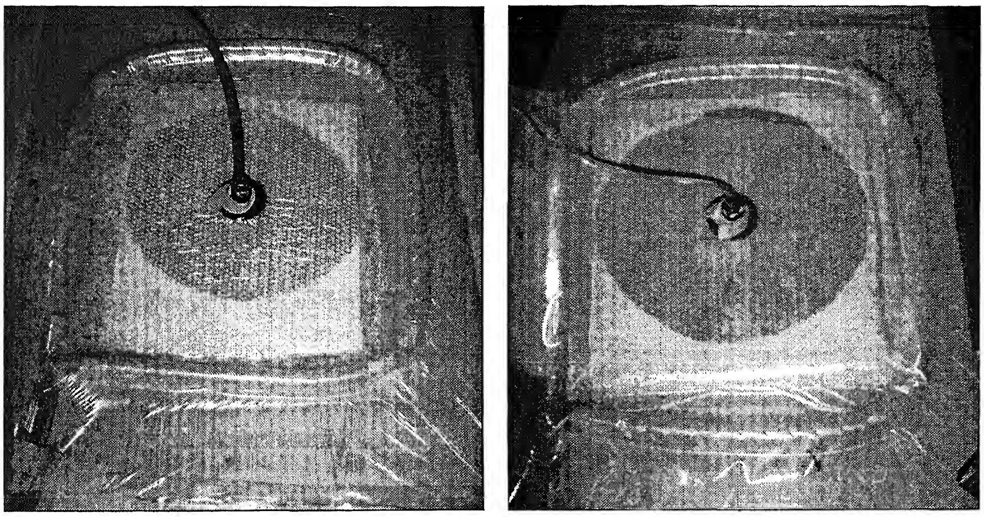


Fig. 6.12(a, b): Infusion using Soric as flow media
a. with thin woven glass fabric, b. with thick woven glass fiber as reinforcement

In Figure 6.13, the vacuum line is extended by using spiral tube and the resin flow is regulated using the omega tube and Enkafusion nylon mat, hence the fasted infusion rate is achieved.

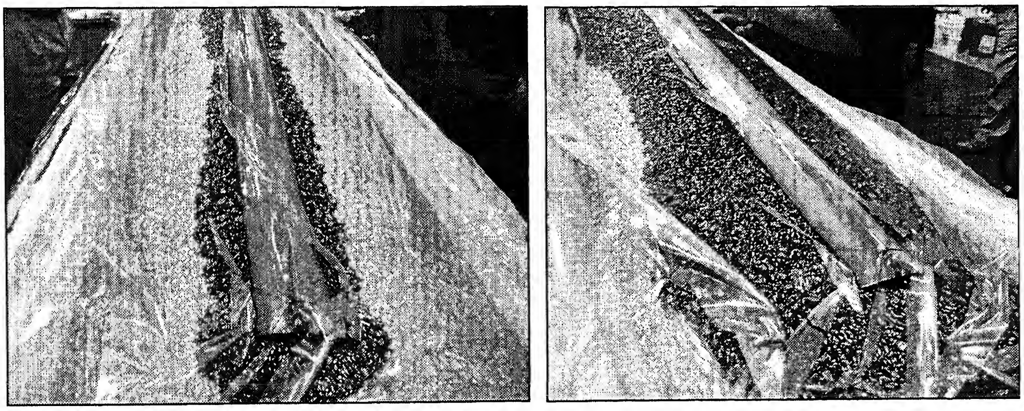


Fig. 6.14(a, b): Resin infusion with omega tubes

6.4 ADVANTAGES

RIM offers several advantages over hand lay-up technique and vacuum bagging, some of these are discussed below:

High Strength:

Strength of a laminate is directly dependent on fiber volume fraction, hence high specific strength is achieved in vacuum infused parts due to 70% reinforcement content in total laminate weight. In addition the vacuum reduces the amount of air and moisture trapped in the laminate.

Low Weight:

This process can reduce the weight of the laminate by 20 to 30%. Because each layer has excellent fiber volume fraction, fewer layers are required to achieve the same strength.

Part Consistency:

Same part can be made over and over by different people with consistency in percentage of reinforcement content, adhesion to the core and other physical and mechanical properties, as vacuum does most of the work of eliminating air, saturating the laminate and providing even pressure to the core, Human errors are minimized.

Quality control:

High degree of quality can be maintained in VARIM parts as laminate stacks can be verified prior to adding the resin and void content is reduced dramatically.

Environmental Advantages:

By the virtue of being a closed molding system the exposure to styrene fumes associated with open molding is eliminated. The limited exposure of the resin through the feed source makes the process more clean, safe and environmental friendly.

6.5 MAJOR PITFALLS

RIM process provides us unlimited set-up time as resin is introduced after dry run trials, but it is somewhat more **complicated**. Vacuum bagging requires the placement of only the vacuum tubing. Vacuum infusion requires not only vacuum tubes but resin inlets as well. Placement of these vacuum and resin lines varies from part to part, and there is no set way. These considerations must be evaluated prior to lay-up, or else the part could be ruined.

It is very easy to destroy a part. Typically, once infusion begins, there is little that can be done to correct any errors. For example, if a leak were to occur, even the smallest amount of air introduced could be potentially fatal to a part. It would probably result in resin pooling, under saturation, or even a complete stoppage of resin flow. Though there are certainly some cases where problems can be corrected, it should not be expected. The best protection from disaster is careful planning.

Due to the complexity and ease of error, RIM is viewed as a **trial-and-error process**. The trick is to carefully document each attempt in order to learn from each trial. Keeping track of the resin flow rates, determine where the resin is reluctant to go and find a way to get it there. Even the smallest modifications can yield drastically different results.

6.6 DIFFERENCE BETWEEN VACUUM BAGGING AND VACUUM INFUSION

Vacuum infusion is superior to vacuum bagging process in many ways. Table 6.1 provides the difference between the two processes

Table 6.1: Difference between Vacuum Bagging and VARIM

	Vacuum Bagging	**VARIM**
1	Is a close molding process except for the initial lay-up.	Is a closed molding process (sealed system typically consists of one hard bottom and one soft bag)
2	Hand lay up or prepregs are required.	Resin is infused in dry reinforcement stack. Hence reducing labor and making process clean and accurate.
3	Void content is reduced as compared to hand lay up.	Void content are even less than vacuum bagging as cavity in evacuated before the resin is infused.
4	Resin to reinforcement ratio is not that high.	70% reinforcement is achieved
5	Strength	High specific strength as less number of layers are required.
6	Weight	Lighter than parts produced in vacuum bagging for the same strength
7	Part consistency (human factor is involved)	Vacuum is the driving force for saturating the laminates.
8	Resin and emissions are exposed to atmosphere	By virtue of close molding it is safe, clean and environmental friendly process.

6.7 CONCLUSION

The advantages offered by RIM makes it suitable for automobile industry. This process can be used for low volume production of vehicles like sports cars; as high degree of consistency is required for such applications. It is preferred to mold parts of larger size in RIM. This process is superior to vacuum bagging and provides ease of fabrication by using dry preforms. The use of core materials as a flow media solves the dual purpose of making stiff structures and achieving high infusion rates.

Chapter 7

CONCLUSION

The automobile industry is one of the core industries in Indian economy, whose prospect is reflective of the economic resilience of the country. With the growth of this industry there is a huge demand of vehicles with novel designs and high fuel efficiency. However, the Indian automobile manufacturers are constraining themselves to the production of limited designs, because of very high investments involved in tooling.

Lightweight sandwich composite materials are finding exciting opportunities in the automotive industry as a means of increasing fuel efficiency. Sandwich composites made of glass fiber reinforced plastic (GFRP) skins with a low density core material in between, are capable to meet the requirements of different automobile panels. The major advantages offered by this material are light weight, high specific strength and high specific stiffness. Also, the tooling cost involved in manufacturing of composite parts is very low.

In the present work light weight automobile panels are designed and developed using different sandwich materials. Encouraging results are marked in reducing the finishing operations of FRP panels. Other manufacturing processes like Resin infusion molding (RIM) was studied and established for obtaining better and consistent FRP parts.

First to understand the requirements of automobile panels, a case study was done. It was found that sandwich GFRP structures are suitable for making car body shells. Along with the advantages offered by composite materials, the benefits of design for manufacturing and assembly were also explored.

A bus bonnet was designed with PU foam sandwich structure along with few test products. It was found that PU sandwiched composite panels possess attractive mechanical properties and are able to meet other requirements of automobile prototyping. To move one step ahead, core mat sandwiches were introduced. The superiority of these structures over PU sandwiching was proved. The core mat structures are also well suited for automobile prototyping. Its capability to take thin sections and ease in fabrication make it superior for several auto panels like car fenders, boot lid etc.

Another important problem with FRP panels was solved by minimizing the involved finishing operations. Following certain guidelines for preparation of mold and component, an optimize process was established for composite part fabrication. Encouraging results were achieved and the panels developed with the process were successfully installed on respective vehicle bodies.

Composite automobile body shells are used for low volume production of vehicles like sports cars. For critical applications the quality consistency of a part should not depend much on worker's skill. In order to achieve consistent parts with better quality control, the Resin Infusion Process (RIM) was established.

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